

TM 9-5000-14

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

NIKE I SYSTEMS COMPUTER PRELAUNCH SECTION AND INITIAL TURN SECTION CIRCUITRY (U)

HEADQUARTERS, 213th AAA GROUP
Pennsylvania National Guard
15th & Allen Streets
Allentown, Pennsylvania



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TM 9-5000-14, Nike I Systems, Computer Prelaunch Section and Initial Turn Section Circuitry (C), is published for the use of all concerned.

The special texts in the TM 9-5000-series are training supplements to those in the TM 9-5001-series which are the basic Army directives for the operation and maintenance of the NIKE I Guided Missile System. In the event of conflict, technical manuals in the TM 9-5001-series will govern.

[AG 413 H (20 Mar 56)]

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For explanation of abbreviations used, see SR 320-50-1.

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CHAPTER 1

THE COMPUTER PRELAUNCH SECTION BLOCK DIAGRAM

Section I. GENERAL DISCUSSION

1. PURPOSE AND SCOPE

a. Purpose. The purpose of this special text is to present to the reader a block diagram and a detailed discussion of the computer prelaunch and initial turn sections.

b. Scope. This text presents the general functioning, mathematical analysis, and detailed circuit operation of each unit of the prelaunch and initial turn sections of the Nike I computer. The block diagram discussion is designed to give the reader an over-all picture of the operation of the section being discussed so that, with the detailed discussions which follow, a complete understanding of the operation of the system may be gained.

2. REFERENCES AND DEFINITIONS

a. References. References to other special texts are of the form TM 9-5000-16 with the appropriate paragraph number. References such as "TM 9-5000-26, page 162" refer to the page or the first of several pages on which a circuit is shown in TM 9-5000-26, Acquisition and Computer Schematics. The abbreviated reference 108C4 refers to zone C4 of page 108 of TM 9-5000-26 (p 11 of TM 9-5000-26). This reference system is used to point out specific items within the schematic. References of the form "16C13" refer to the sheet number and zone number system which is explained on page 11 of TM 9-5000-26. This reference system has been avoided wherever possible.

b. Definitions. The definitions of the symbols and abbreviations used within the body of this text will be found in appendix I of TM 9-5000-13.

3. REVIEW

The antiaircraft problem has always been complex. This complexity is due in great part to the engagement, by troops on the ground, of a target in the air capable of rapid maneuver in any of three directions. The solution of this problem using medium and heavy antiaircraft artillery considers both the movement of the target and the ballistics of the projectile. However, after an artillery round is fired all influence over that round ceases. This fact places a definite limitation upon the effectiveness of the gun solution to the antiaircraft problem.

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With the introduction of the surface-to-air missile a new factor is introduced into the antiaircraft problem. This factor is the fact that the missile may be steered in flight. This permits the missile to be steered to counter any maneuver of the target following the firing of the projectile. To perform the involved calculations required to direct such a missile, an electromechanical analog computer has been devised. This computer is divided functionally into three sections: the prelaunch section, the initial turn section, and the steering section. Before the missile is launched, the prelaunch section functions somewhat like the conventional antiaircraft gun computer. Its purpose is to predict the azimuth of the intercept point of the target and the missile. This reference azimuth, called gyro azimuth, is used to guide the missile toward the predicted intercept point during the initial portion of its flight phase. Gyro azimuth is used as a reference in the highly adaptable fire control system which is capable of guiding the missile to engage targets from any direction. This azimuth, which remains constant throughout the flight of the missile, may be considered to be the connecting link between the ground equipment and the missile, since it is used as a constant reference during the flight phase; proper operation of the initial turn and steering sections depends upon it. The initial turn section controls the missile immediately after launch. Since the booster must be dropped into an area where the least damage to friendly installations will occur, it is necessary to launch the missile in the same direction for all approaching targets. Under these circumstances, it is desirable that the missile be brought onto the correct flight path as soon as possible. This is the primary function of the initial turn section. With targets on certain flight paths, the most direct course of the missile toward the intercept point might take it over the missile-tracking radar. If this should occur, the maximum tracking rates of the missile-tracking radar might be exceeded, causing the system to lose control of the missile. The second function of the initial turn section then is to determine whether this situation exists, and if it does, to cause the missile to skirt the missile-tracking radar at a safe distance. The steering section of the computer continuously determines the distance between the target and the missile, the time remaining to intercept, and the target-to-missile closing velocity. From these data it determines the steering errors which exist between the missile flight path and the target flight path. The section then issues orders to cause the missile to assume a flight path that will intercept the target.

Section II. BLOCK DIAGRAM DISCUSSION

4. GENERAL

The prelaunch section of the computer is designed to determine a point in space toward which the missile should be directed to intercept the target at the end of the predicted time of flight. This prediction is based on target present

position, target immediate past performance, and missile ballistics. The pre-launch section determines the predicted time of flight, the gyro azimuth (azimuth to the predicted intercept point from the designated launcher), and the predicted intercept point. The gyro azimuth is made available to the missile to orient the missile roll-amount gyro prior to flight, and to the initial turn and steering sections of the computer to act as a reference between the missile in flight and the computer on the ground. The predicted time of flight is sent to the steering section of the computer for use as the initial solution of the time-to-intercept problem. The intercept point solution is used in the prelaunch section to determine the gyro azimuth, and is sent to the plotting boards as information for the battery control officer.

5. THE PRELAUNCH SECTION BLOCK DIAGRAM (TM 9-5000-26, p 37)

The prelaunch section of the computer consists of the following units:

- a. The target coordinate converter.
- b. The missile coordinate converter.
- c. The launcher parallax unit.
- d. The target prelaunch differentiator.
- e. The intercept point solver.
- f. The dead-time unit.
- g. The ballistic elevation servo.
- h. The gyro azimuth servo.
- i. The time-of-flight predictor.

This section will discuss the general functioning and mathematical operation of each of these units.

6. THE TARGET COORDINATE CONVERTER

Elements of the target coordinate converter are found both in the target-tracking radar and in the computer. Slant range is supplied from the range unit assembly of the target-tracking radar and is sent to sine and cosine cards of the elevation data potentiometer in the target-tracking radar. Relationships (1) and (2) can be obtained from figure 1.

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$$H_T = D_T \sin E_T \quad (1)$$

$$R_T = D_T \cos E_T. \quad (2)$$

The brush arms of the elevation data potentiometer are positioned according to the present elevation angle of the target from the target-tracking radar, and H_T and R_T are obtained as outputs. R_T is not used directly but is transmitted to sine and cosine cards in the azimuth data potentiometer. Relationships (3) and (4) are evident from figure 2.

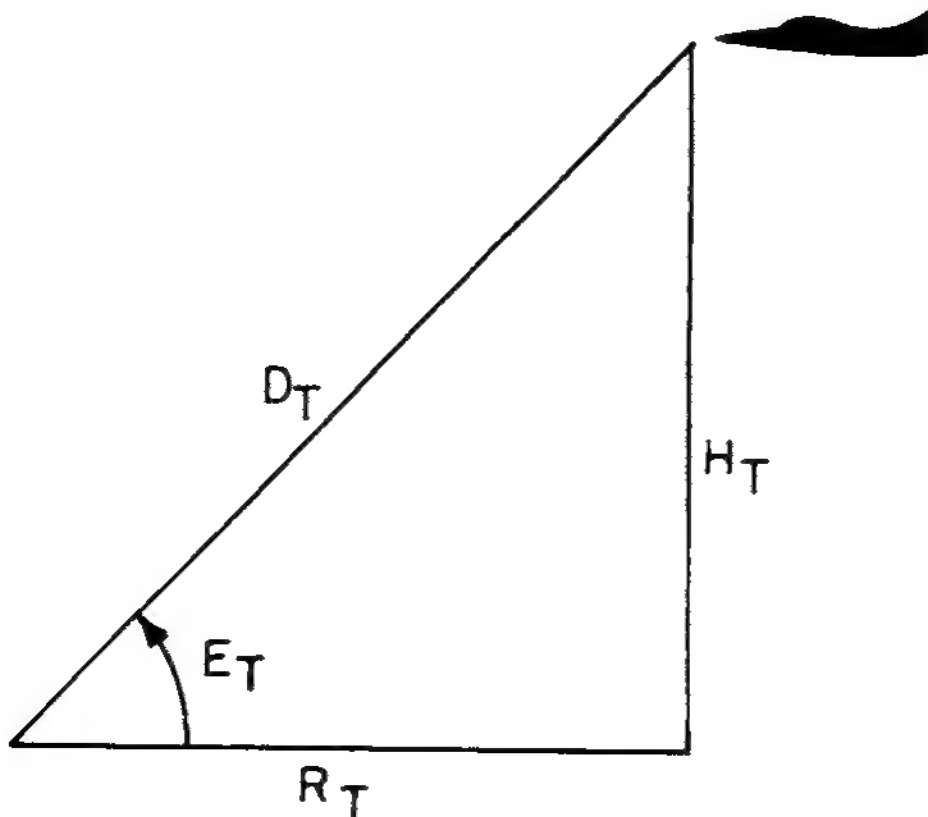


Figure 1. Computation of R_T and H_T .

$$X_T = R_T \sin A_T \quad (3)$$

$$Y_T = R_T \cos A_T. \quad (4)$$

Brush arms of the azimuth data potentiometer are positioned according to the present azimuth of the aircraft from the target-tracking radar, and X_T and Y_T are obtained as outputs. The present rectangular coordinate data of the target,

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X_T , Y_T , and H_T , are sent to the target prelaunch differentiator and the intercept point solver. The symbol, T' , shown in figure 2 is the projection of the present target position on the horizontal plane.

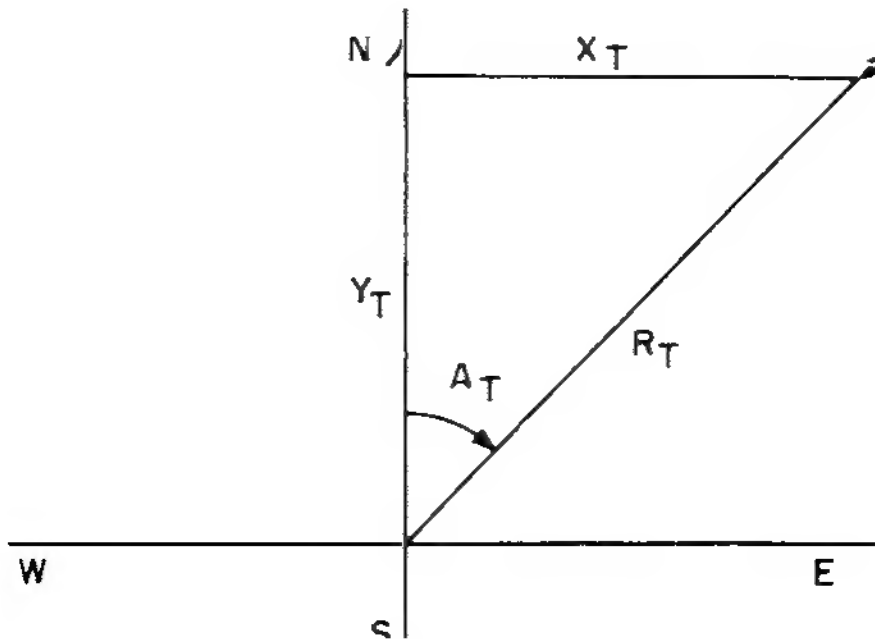


Figure 2. Computation of X_T and Y_T .

7. TARGET PRELAUNCH DIFFERENTIATOR

The purpose of the target prelaunch differentiator is to obtain the rate of change of target position and to produce voltages proportional to this rate. The inputs to the section are X_T , Y_T , and H_T . The voltages developed by the target prelaunch differentiator are \dot{X}_P , \dot{Y}_P , and \dot{H}_P . These outputs are sent to the intercept point solver.

8. LAUNCHER PARALLAX UNIT

The purpose of the launcher parallax unit is to supply to the intercept point solver voltages representing the rectangular coordinates of the launcher with respect to the target-tracking radar. This permits development of more accurate data representing launcher-to-target distance. Prior to automatic tracking of the missile, the outputs are obtained from three potentiometers which are handset, using survey data. After the missile is tracked automatically, the missile coordinate converter supplies X_M and Y_M to the intercept point solver.

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By relay operation, X_M and Y_M replace the output from the handset potentiometers in X and Y . The outputs from the launcher parallax unit are always referred to as X_L , Y_L , and H_L regardless of their source. These outputs are sent to the intercept point solver.

9. MISSILE COORDINATE CONVERTER

The missile coordinate converter functions in the same manner as the target coordinate converter. Its purpose is to convert missile spherical coordinate data to rectangular coordinate data. The inputs in spherical coordinates are D_M , A_M , and E_M . These coordinates are all measured from the missile-tracking radar. The missile coordinate converter produces X_M , Y_M , and H_M from the spherical coordinate input data. X_M and Y_M are the only data used in the solution of the prelaunch problem and are sent to the intercept point solver through relay contacts. H_M is used by a circuit which detects MISSILE AWAY and is not used in the prelaunch section.

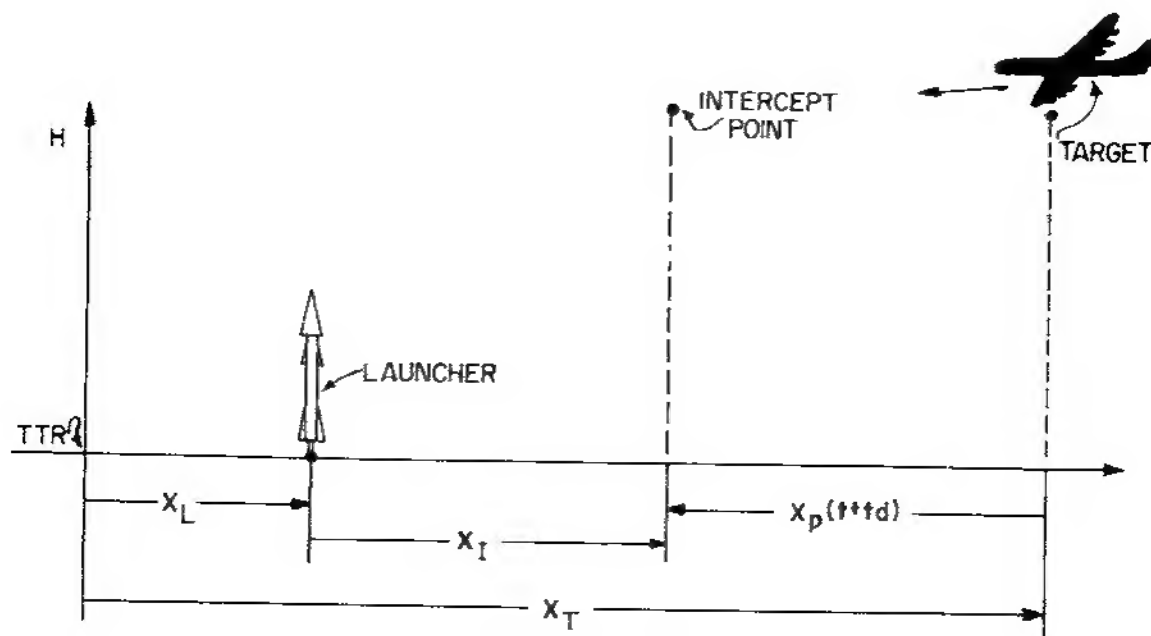


Figure 3. Calculation of predicted intercept point coordinates.

10. INTERCEPT POINT SOLVER

The purpose of the intercept point solver is to predict the intercept point coordinates with respect to the launcher. The inputs to the section are as follows:

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Launcher position data: X_L , Y_L , and H_L

Target present position data: X_T , Y_T , and H_T

Target velocity: \dot{X}_P , \dot{Y}_P , and \dot{H}_P

Predicted time of flight: t

Dead time: t_d .

In the computation of the intercept point rectangular coordinates, account is taken of the speed of the target and the flight characteristics of the missile (fig 3). In this diagram the predicted intercept point is shown calculated using the target-tracking radar as a reference. Consider X_I singly for simplicity. This quantity will be given by the following equation:

$$X_I = X_T - X_L + \dot{X}_P (t + t_d). \quad (5)$$

Y_I and H_I are obtained similarly. In the prelaunch problem, dead time, t_d , is a constant 7 seconds. Time of flight may vary from zero to 100 seconds. X_I and Y_I are sent to the gyro azimuth servo and H_I to the ballistic circuits.

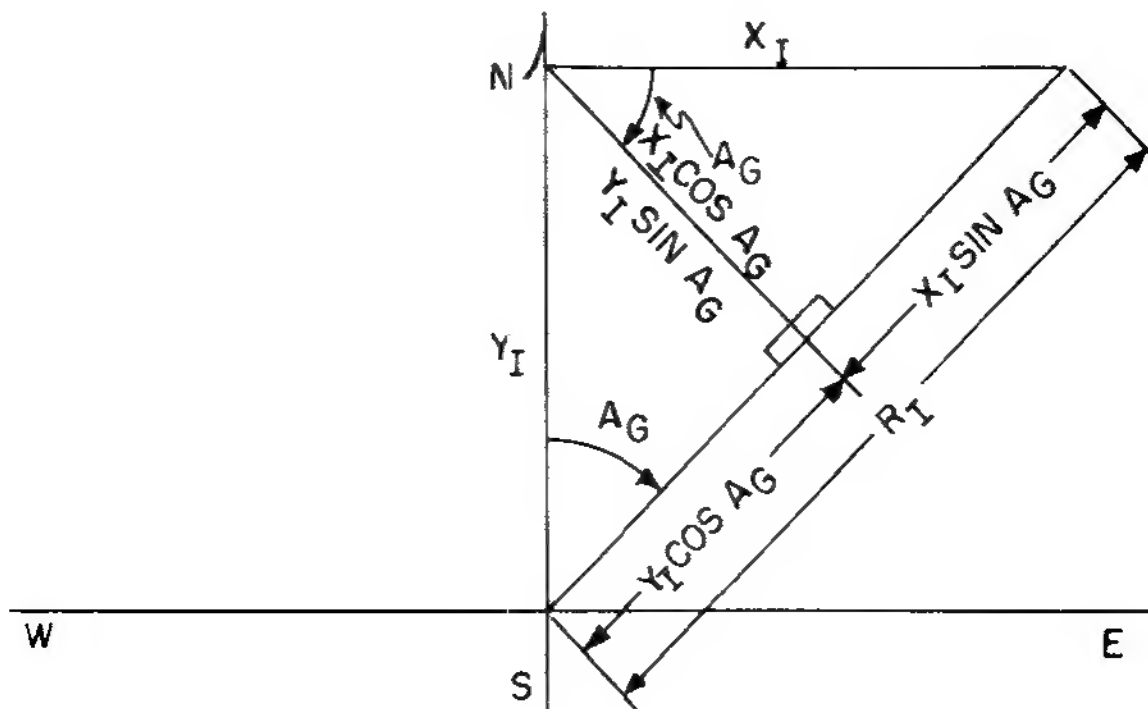


Figure 4. Solving for gyro azimuth.

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11. GYRO AZIMUTH SERVO

The gyro azimuth servo determines the azimuth angle of the predicted intercept point from X_I , Y_I , and the simple trigonometry relating the sides and angles of a right triangle. From figure 4 it is evident that

$$\tan A_G = \frac{X_I}{Y_I} \quad (6)$$

and from trigonometry,

$$\tan A_G = \frac{\sin A_G}{\cos A_G} \quad (7)$$

Therefore,

$$\frac{X_I}{Y_I} = \frac{\sin A_G}{\cos A_G} \quad (8)$$

or

$$X_I \cos A_G = Y_I \sin A_G \quad (9)$$

The same equation may be obtained by dropping the perpendicular shown in figure 4. The gyro azimuth servo equates $X_I \cos A_G$ and $Y_I \sin A_G$ to obtain A_G . From figure 4 it is apparent that $X_I \sin A_G + Y_I \cos A_G$ equals R_I , the horizontal range to the intercept point. R_I is sent from the A_G servo to the time-of-flight predictor.

12. TIME OF-FLIGHT PREDICTOR

Time of flight of the missile is derived in the computer prelaunch section as a function of horizontal range R_I . The servo equates positive and negative values of R_I for a solution of time of flight. Minus R_I is obtained from the A_G servo as described in the preceding paragraph. Plus R_I enters the time-of-flight predictor from the ballistic circuits in the form of $R_B + D_B \cos B$. The expression, $R_B + D_B \cos B$, is a complex term which is a synthesis of R_I obtained from R_I , t , and empirical data in the ballistic circuits. Time is sent as a shaft position to the intercept point solver and to the ballistic circuits.

13. DEAD-TIME UNIT

The dead time unit is essentially a delay timer provided in the Nike I computer for two purposes: first, to provide a smooth transition from the prelaunch

time of-flight solution to the steering time-to-intercept solution; second, to provide a means of rejecting the missile should it fail to launch within a reasonable time. Dead time, t_d , is a constant 7 seconds. Missile reject will take place automatically at 5 seconds after FIRE if the MISSILE AWAY signal has not been received.

14. BALLISTIC CIRCUITS

The ballistic circuits of the Nike I computer consist of a servo system and several empirically derived potentiometer networks. Their purpose is to synthesize a voltage which represents positive R_I . To achieve this aim, H_I , a shaft position representing time of flight, and a voltage $(+t)$ representing time of flight, are applied to the circuit. $R_B + D_B \cos B$ then is obtained. This term is equal to $+R_I$. The purpose of this synthesis is to make the computation more accurate than would have been possible had $-R_I$ been used alone in the time-of-flight predictor. The height of the intercept point influences the time of flight of the missile and therefore is used in the synthesis.

15. OUTPUTS TO THE PLOTTING BOARDS

During the prelaunch phase, the plotting boards are supplied with data from the prelaunch section of the computer. Voltages representing X_T , Y_T , X_L , Y_L , X_I , and Y_I are sent to the horizontal plotting board for proper positioning of the pens. In addition, voltages which represent t and H_I are sent to the vertical plotting boards.

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CHAPTER 2

PRELAUNCH SECTION DETAILED CIRCUITRY

Section I. TARGET COORDINATE CONVERTER

16. GENERAL

The purpose of the target coordinate converter is to convert the target present position data from spherical to rectangular coordinates. It is composed of 3 spiral potentiometers and 10 DC amplifiers. The range data potentiometer is located in the relay range and receiver cabinet in the radar control trailer. The azimuth and elevation data potentiometers are located in the azimuth and elevation data converter units on the target tracking radar antenna trailer. The 10 DC amplifiers are located in the computer amplifier cabinet. For easy identification, the position of each DC amplifier on the equipment frame is labeled according to the function of the amplifier. For example, the D_T amplifier is clearly stamped $-D_T$. There are three inputs to the coordinate converter: D_T , E_T , and A_T . These are shaft positions determined by mechanical positioning of the target antenna and range unit. Essentially there are three outputs (X_T , Y_T , and H_T); however, both positive and negative values of each of these outputs are needed. Each output also may have more than one use in the computer. The scale factor used in the coordinate converter is determined by the voltage applied to the range data potentiometer and the maximum range it is designed to represent. The voltage applied to the range data potentiometer is the regulated scale factor voltage, $+106 \frac{2}{3}$ volts. The maximum design range is $106,666 \frac{2}{3}$ yards. The maximum range data which can be supplied by the range data potentiometer is limited to 100,000 yards by the range limitations of the TTR. The scale factor is 1 millivolt (0.001 volt) per yard.

17. MATHEMATICAL ANALYSIS

Figure 5 illustrates the method by which spherical coordinates are converted to rectangular coordinates. It can be readily proved that a mathematical relationship exists between spherical and rectangular coordinates, and that the following equations are true:

$$H_T = D_T \sin E_T \text{ (the altitude of the target above the TTR)} \quad (10)$$

$$R_T = D_T \cos E_T \text{ (the ground range of the target from the TTR)} \quad (11)$$

$$X_T = R_T \sin A_T \text{ (east west component of target position in earth coordinates)} \quad (12)$$

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$$Y_T = R_T \cos A_T \quad (\text{north-south component of target in earth coordinates}). \quad (13)$$

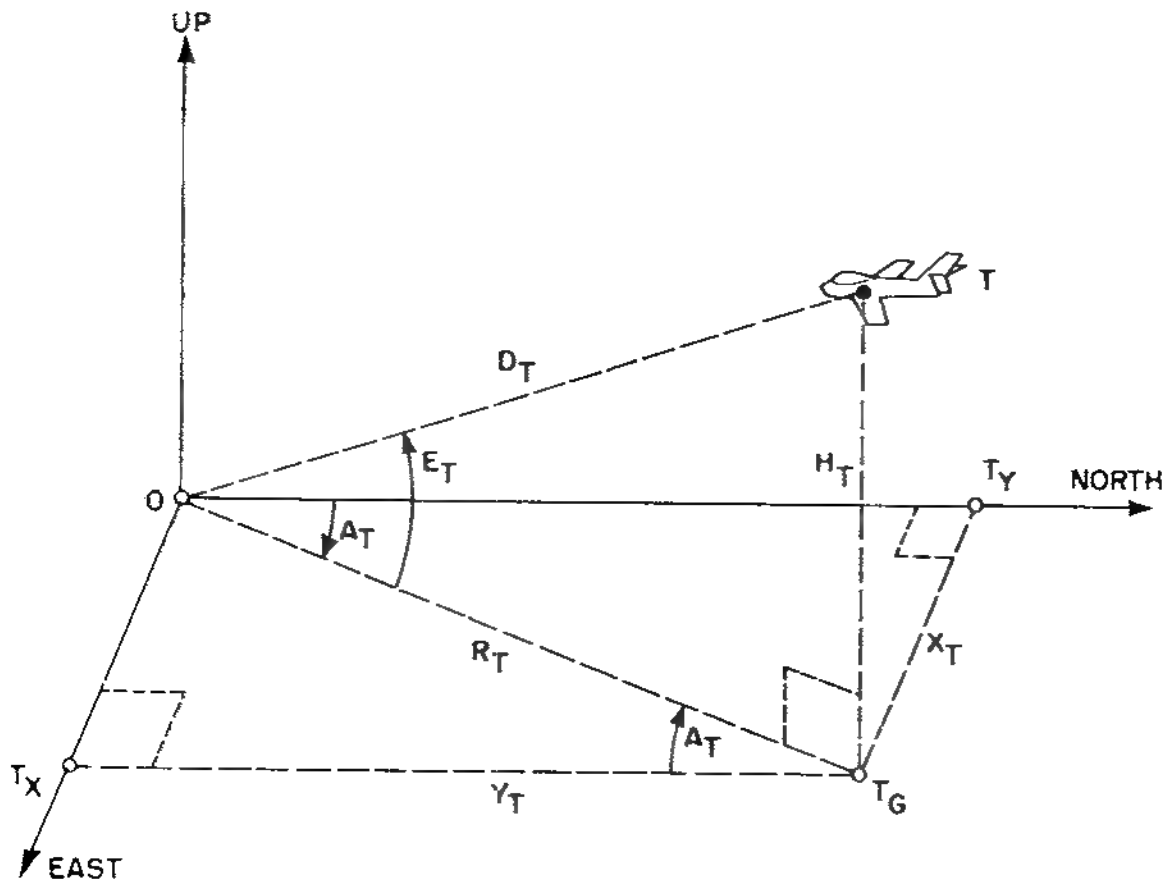


Figure 5. Resolution of target present position data into rectangular coordinates.

18. SIMPLIFIED FUNCTIONAL OPERATION (TM 9-5000-26, pp 40 and 41)

a. Range potentiometer. The target range data potentiometer contains a linearly wound card to which $+105 \frac{2}{3}$ volts is applied. The range servo of the TTR positions a single brush arm which picks off a voltage proportional to the slant range to the target. D_T (slant range) is always positive regardless of the target azimuth, and the voltage representing D_T taken from the range data potentiometer is always positive. The elevation data potentiometer requires that D_T be supplied to it as both a positive and negative voltage. Two DC amplifiers are used to perform this function and to supply the positive and negative voltages representing D_T to the elevation data potentiometer. They also provide

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the necessary isolation to prevent loading the range data potentiometer. It can readily be seen that maintaining a very accurate D_T is extremely vital to computer accuracy. In addition to isolating the range data potentiometer to maintain D_T accuracy, shielded cables are used for transmitting the D_T voltage from the radar control trailer to the battery control trailer. These shields are maintained at $+D_T$ potential using the output of the $+D_T$ amplifier. This type of shielding is referred to as driven shielding.

b. Elevation data potentiometer. This potentiometer is a sine cosine spiral potentiometer which was described and explained in TM 9-5000-13. It receives two input voltages representing $+D_T$ and $-D_T$. The two brush arms (one sine, one cosine) are mechanically positioned to the elevation angle as the TTR tracks the target. The brush arms pick off voltages representing $-D_T \sin E_T$ which equals H_T , and $-D_T \cos E_T$ which equals R_T . An explanation is required to clarify the meaning of positive or negative signs preceding the symbol for an element of coordinate data. For example, a symbol such as H_T does not necessarily mean that the voltage analog is negative, but it means that the representative voltage is negative when the coordinate element it represents is a positive value. Outputs of H_T are taken at three separate places. Output H_T is taken directly from the elevation data potentiometer and sent to the closing speed solver of the computer steering section. Output $+H_T$ is taken from the $+H_T$ amplifier and sent to the intercept point solver. Another $-H_T$ output is taken from the $-H_T$ amplifier and sent to the target prelaunch differentiator and to the target steering differentiator. The $-H_T$ voltage from the $-H_T$ amplifier supplies the driven shield of the cable transmitting $-D_T \sin E_T$. Voltages representing $+R_T$ and $-R_T$ are developed from the $-D_T \cos E_T$ output of the elevation data potentiometer, using two DC amplifiers as in the development of $+H_T$ and $-H_T$. Voltages representing $+R_T$ and $-R_T$ are applied to the target azimuth data potentiometer.

c. Azimuth data potentiometer. The azimuth data potentiometer is also a sine-cosine spiral potentiometer. The two brush arms of the azimuth data potentiometer are mechanically positioned to the azimuth angle as the TTR tracks the target. Voltages picked off by the brush arms represent $-R_T \sin A_T$ and $-R_T \cos A_T$. As explained above, the positive or negative sign preceding a symbol for coordinate data establishes the polarity of the voltage representing that element of data.

$$R_T \sin A_T = -X_T, \text{ and } -R_T \cos A_T = -Y_T.$$

Values of X_T and Y_T are each taken from three separate places. Voltages $-X_T$ and $-Y_T$, taken directly from the azimuth data potentiometer, are sent to the closing speed solver. Voltages $+X_T$ and $+Y_T$, taken from the $+X_T$ and $+Y_T$

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amplifiers, are sent to the intercept point solver. Voltages $-X_T$ and $-Y_T$, taken from the X_T and $-Y_T$ amplifiers, are sent to the target prelaunch and target steering differentiators.

19. DETAILED FUNCTIONAL OPERATION (TM 9-5000-25, p 129)

a. Range data potentiometer. This potentiometer can be found on the schematic near the bottom center of the page. The range card is shown as a $2 \frac{1}{2}$ turn spiral card, with $2 \frac{11}{32}$ turns representing 100,000 yards of range. This ratio can be seen by examining the gearing between the range data potentiometer and the phase capacitor at the upper left of the page. Later study of the TTR will show that one complete revolution of the phase capacitor shaft will change radar range by 2,000 yards. The gearing ratio between the range data potentiometer and the phase capacitor is 512 to 24. One complete revolution of the range data potentiometer brush arm is equivalent to:

$$\frac{512}{24} \times 2,000 \text{ yards} = 42,666 \frac{2}{3} \text{ yards.}$$

Then, $2 \frac{11}{32}$ turns are equivalent to:

$$2 \frac{11}{32} \times 42,666 \frac{2}{3} \text{ yards} = 100,000 \text{ yards.}$$

Electrically the card is linear and connected between $+106 \frac{2}{3}$ volts and ground; to increase range, the brush arm moves from ground to $106 \frac{2}{3}$ volts in $2 \frac{1}{2}$ revolutions. At any point along the card, the voltage picked off at the brush arm equals the number of revolutions the brush arm has made to that point divided by $2 \frac{1}{2}$, the maximum number of revolutions. For example, the voltage picked off for a range of 100,000 yards will be:

$$\frac{2 \frac{11}{32}}{2 \frac{1}{2}} \times 106 \frac{2}{3} \text{ volts} = 100 \text{ volts.}$$

Then the scale factor is:

$$\frac{100 \text{ volts}}{100,000 \text{ yards}} = 0.001 \text{ volt per yard, or} \\ 1 \text{ millivolt per yard.}$$

b. Driven shielding. Refer to 41B4 Notice the lead just at the right of terminal 76. This is the lead which supplies $+D_T$ to the driven shield of cable-run 34 and the other cable segments transmitting D_T . These carrier cables are coaxial, with distributed capacitance between the inner conductor and the outer shield. If the outer shield were grounded, for every change in the value of D_T there would be an additional flow of current to charge the

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capacitance. Additional current would tend to load the range data potentiometer and create an error in the $+D_T$ voltage. By driving the shield at a voltage equivalent to $+D_T$, the effect of capacitance is minimized.

c. Various leads. Refer to 41B5. Here $+D_T$ and $-D_T$ leads are referred to 2B4 (39B4). These voltages are used to replace $+D_M$ and $-D_M$ data when the ORIENT CHECK switch is operated. At the right of the $+D_T$ amplifier is reference 16C5 (29C6), a connection from the amplifier output to the zero check circuit, which is provided for zero checking the amplifier. Most DC amplifiers of the computer are connected to the zero check circuit. The input network to the $+R_T$ amplifier should show a 0.5-megohm input resistor and a ground connected, 5-megohm resistor in the network. This 5-megohm resistor and ground connection is provided to give balanced loading for the elevation data potentiometer. Reference to the potentiometer at 41B1 shows that each contact arm has a 6 megohm load resistor within the elevation data unit, and that the upper lead to the $+H_T$ amplifier is connected to an input resistor of 5.0 megohms. The lower lead to the $+R_T$ amplifier should be shown connected to an input resistor of 0.5 megohm. The lower lead connects also to a grounded 5 megohm resistor in the $+R_T$ network. At 41B9 the $-H_T$ connection to the H/t network in the closing speed solver is shown. The upper lead is connected here to a 0.5-megohm input resistor. Thus, the elevation data potentiometer works into a balanced load. Refer to the leads that are labeled HFDC, XFDC, and YFDC. These leads are connected just to the left of the input networks, $-H_T$, $-Y_T$, and $-X_T$. By tracing these leads to reference 41A4, it can be found that these data are sent to the radar range and receiver cabinet and will be available for future use with the automatic fire direction center. Lead connections for transmitting data to the intercept point solver are found at the right of the $+X_T$, $+Y_T$, and $+H_T$ amplifiers. These data are sent through the static test relay panel, shown represented by dotted blocks marked "Prel Switch Relay Panel" and referred to 23C10 (61C10) and 23D10 (61D10).

d. Relays. The operation of three relays controls the transmission of these data to the intercept point solver. Relays K15 and K23 must be energized at the start of the engagement. Relay K15 is an action relay and is energized when the COMPUTER CONDITION switch is in the ACTION position. Relay K23 is the not-standby relay and is energized when a target is tracked. Relay K17 is used for tracking tests. Connections for target present position data sent to the plotting boards are shown at the right of page 41. Data to the target steering and prelaunch differentiators can be traced to the right on page 41, beginning at coordinate 8.

20. MECHANICAL OPERATION (TM 9-5000-26, pp 43 and 45)

Refer to the mechanical schematics for the azimuth and elevation data units. The two units appear to be nearly identical. Both azimuth and elevation data potentiometers are constructed with 2 1/2-turn spiral sine cosine cards. An examination of the gearing schematic will show that the gear ratio between the TTR antenna shaft and the potentiometer shaft is 1:5. The spiral cards are designed to represent 3,200 angular mils. Both the azimuth and elevation potentiometers are constructed to supply data representing a complete 6,400-mil movement of the TTR antenna. Switches are provided to rerun the cards after a 3,200-mil movement. Data from the elevation potentiometer are limited to from approximately -200 to +1,590 mils for normal operation by the elevation limits of the TTR antenna. For orientation purposes the elevation limits can be extended from -200 to +3,360 mils.

Section II. MISSILE COORDINATE CONVERTER

21. GENERAL

a. Purpose. The purpose of the missile coordinate converter is to convert the missile present position data from spherical to rectangular coordinates. It is almost an exact duplicate of the target coordinate converter, even to interchangeability of components.

b. Components. The three data potentiometers are located with the MTR components, the ten DC amplifiers are located on the left equipment frame in the computer amplifier cabinet. The range data potentiometer is energized by the scale factor voltage and supplies range data as does the target range data potentiometer; however, the maximum value of D_M is limited by the MTR range servo system.

c. Input data. The inputs are D_M , E_M , and A_M and the outputs are X_M , Y_M , and H_M .

d. Output data. The scale factor for the output data is 1 millivolt per yard. This data is sent to the following places: $+H_M$ to the H/t network in the closing speed solver; $-H_M$ to the missile away circuit and to the missile differentiator circuit; $+X_M$ and $+Y_M$ from the azimuth data potentiometer to the X/t and Y/t networks in the closing speed solver; $-X_M$ and $-Y_M$ from the X_M and Y_M amplifiers to the initial turn panel and to the missile differentiators; $+X_M$ and $+Y_M$ from the $+X_M$ and $+Y_M$ amplifiers to the initial turn circuit.

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22. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, p 39)

a. Common ground. At terminal 109 39A4 a common ground is established for the missile range data potentiometer and the target range data potentiometer.

b. Orient check switch. Refer to 39B5 and C5. Here dotted blocks representing the relay and limiter panel are shown. Relay K1 is controlled by the ORIENT CHECK switch. When K1 is energized, it substitutes $+D_T$ and $-D_T$ for $+D_M$ and $-D_M$ going to the missile elevation potentiometer, and substitutes $+R_T$ and $-R_T$ for $+R_M$ and $-R_M$ data going to the missile azimuth potentiometer. The purpose of the data substitution is to check the orientation of the TTR and MTR.

c. Missile-away circuit. Locate the following: K59, C59, C93, K1, and the resistor network at 39B7. These circuit elements, together with the $-H_M$ amplifier and input network, constitute the missile-away circuit which is discussed in detail in chapter 5. This circuit allows the H_M amplifier to serve as the missile-away detector during the prelaunch phase and then perform its normal function of supplying missile altitude data during the missile flight phase.

d. Plotting board and closing speed solver data. Plotting board data are taken at P321 terminals 283 and 281, and terminals 282 and 284. Data to the closing speed solver are taken at 39B6 and 39D4. These points are identified by dotted blocks labeled H/t net, X/t net, and Y/t net.

e. Intercept point solver data. Data outputs to the intercept point solver are shown at 39D6 and are identified by dotted blocks of the prelaunch computer switching relay panel. Relays on this panel controlling these data are shown in detail on page 56 of TM 9-5000-26. Here dotted blocks of the $-X_{H1}$ and $-Y_{H1}$ amplifiers are found, and it can be seen that missile data to the intercept point solver under normal operating conditions, are controlled by the operation of three relays: K18, K24, and K16. Through the operation of these relays, data are supplied to the intercept point solver in the following sequence: X_L and Y_L from the launcher parallax handset potentiometers are supplied at ACTION when K16 is energized; missile coordinate data, $-X_M$ and $-Y_M$, are substituted for X_L and Y_L at MISSILE TRACKED when K18 is energized. These remain as inputs to the intercept point solver until MISSILE AWAY PLUS 4 SECONDS when K24 is energized, replacing X_M and Y_M with launcher handset potentiometer data X_L and $-Y_L$. This is part of resetting the prelaunch section of the computer. Data to the missile differentiator are taken at 39C8, 39C6, and 39D6.

Section III. THE +S-VOLTAGE REGULATOR

23. GENERAL

The purpose of the +S-voltage regulator is to establish and maintain with great accuracy the scale factor voltage (+S) used by the computer. The +S-voltage regulator is composed of a DC amplifier, a special input network, and a regulator stage, including V20. The entire +S-regulator is located on the left equipment frame in the computer amplifier cabinet. V20 is mounted on the equipment frame directly above the +S-amplifier. Power requirements, exclusive of the normal power requirements of a DC amplifier are: 250 volts from the +250-volt regulator to the input network of the DC amplifier, and +320 volts and -320 volts to V20. The regulated 106 2/3 volts in the output is applied to the target and missile range data potentiometers, to the potentiometers in the time-to intercept servo that are used to obtain a voltage analogous to time to intercept, and to the second-per-second bias network in the velocity feedback loop of the time to-intercept servo.

24. SIMPLIFIED FUNCTIONAL OPERATION (TM 9-5000-26, p 162)

a. The DC amplifier. To maintain its required accuracy the +S voltage regulator must have a high gain. This requirement is best fulfilled by use of a DC amplifier. The total load on the +S regulator is approximately 10,000 ohms. The output stage of the DC amplifier cannot deliver enough power to this load. Therefore, a series regulator stage using V20 (12AU7) as a cathode follower is connected to the output of the DC amplifier. The DC amplifier acts as a pre amplifier for the regulator tube.

b. Feedback voltage. The precision input and feedback resistors of the regulator are contained in an oven to insure that ambient temperature changes will not affect the output voltage. The feedback voltage is taken at the cathode of V20. If the gain of V20 is assumed to be 1, the over all gain of the DC amplifier is:

$$\frac{R_B}{R_{in}} = \frac{0.42666 \text{ megohm}}{1.00000 \text{ megohm}} = 0.42666.$$

When the 250 volts is applied at the input, the output voltage can then be determined by multiplying the input voltage by the gain and inverting the sign. Thus 250 volts x 0.42666 gives +106 2/3 volts output. If the load resistance of the +S voltage regulator decreases, the voltage on the cathode of V20 will decrease. This will cause the feedback voltage to become less positive and the input voltage at the grid of the DC amplifier to become more negative, increasing current flow through V20 and increasing the voltage at its cathode to the proper value.

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25. DETAILED CIRCUIT FUNCTIONING

The negative 250 volt input applied at terminal 3 of the input network comes from the +250-volt regulator through contacts of relay K2 on the relay and limiter panel. When K2 (162D3) is energized by the ZERO CHECK switch, ground is applied to the +S amplifier for zero checking the amplifier. At 162D6 the connection to the ZERO CHECK meter is labeled 16A4. Capacitor C20 (162D5) connected from grid to cathode of V20 prevents high frequency oscillations from developing. The 1,000-ohm resistors in the grid leads of V20 limit grid current and prevent parasitic oscillations. The +S voltage output to the second-per-second bias network is shown at 162D6. The output to potentiometer cards TC-14B and TF-6 in the time-to-intercept servo is at terminal 237.

Section IV. LAUNCHER PARALLAX UNIT

26. GENERAL

The purpose of the launcher parallax unit is to supply, to the intercept point solver, coordinate data from handset potentiometers representing the location of the launcher area with respect to the TTR. It is desirable that the predicted intercept point be computed with respect to the exact location from which the missile is to be launched. Until the designated missile is tracked by the MTR, the exact missile position data are not available. Therefore, the launcher parallax unit supplies data which represent the coordinates of the geometric center of the launcher area. After a missile is tracked by the MTR, the data from the launcher parallax unit are replaced by the X_M and Y_M data through relay contacts. This data is called X_L and Y_L regardless of its source. Since the height of each launcher position in the launcher area will not vary greatly in most cases, it is not necessary to refine the H_L data to the exact missile height. The three potentiometers of the launcher parallax unit are located on the computer control panel. The maximum data setting in each coordinate is +6,000 yards. The scale factor is 1 millivolt per yard.

27. MATHEMATICAL ANALYSIS

To determine the intercept point and the time of flight of the missile, the distance between the target and the missile must be known. Since the launcher holding the missile may be up to 3 miles from the TTR, the launcher-to-TTR distance must be considered in the computation of the intercept point. The intercept point is then determined with respect to the launcher position. Figure 6 illustrates the problem of the effect of launcher parallax. With the TTR position as the origin of coordinates, a condition is shown where both the target and

the missile location are in the first quadrant. The positions for both target and missile are resolved into rectangular coordinates. For simplicity of discussion, consider the X coordinate only. X_T is the target coordinate. X_L is the

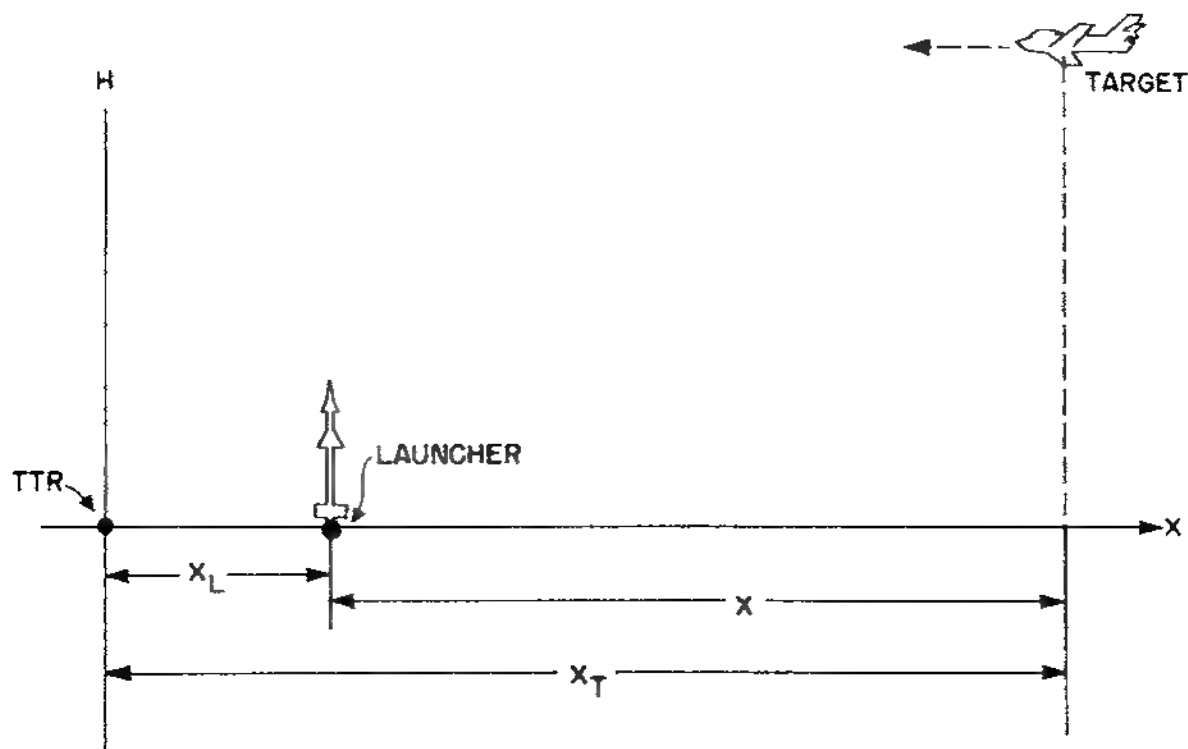


Figure 6. Calculation of launcher-to-target distance.

launcher coordinate. The distance desired is the X distance between the missile and target positions. This is calculated by subtracting the position of the launcher from the position of the target: $X = X_T - X_L$. Y and H are similarly determined by using $Y = Y_T - Y_L$ and $H = H_T - H_L$.

28. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, p 50)

The scale factor of the launcher parallax unit is 1 millivolt per yard. To calculate the maximum range which may be indicated by the handset potentiometers, the potential across the potentiometer must be known. The resistance between the ground point and one end of the potentiometer card is 6,500 ohms. There are three of these cards in parallel; therefore, the total resistance between the ends of the cards and ground is:

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$$R = \frac{1}{\frac{1}{6,500} + \frac{1}{6,500} + \frac{1}{6,500}} = 2,166 \frac{2}{3} \text{ ohms.}$$

The resistance in series, between the top of the potentiometer cards and 250 volts, is 88,400 ohms. Thus, the total resistance between ground and 250 volts is 90,566 $\frac{2}{3}$ ohms. The voltage across the card is determined by the formula.

$$+250 \text{ volts} \times \frac{2,166 \frac{2}{3} \text{ ohms}}{90,566 \frac{2}{3} \text{ ohms}} = 5.981 \text{ volts.}$$

Using the scale factor of 1 millivolt per yard, this allows a maximum offset distance of 5,981 yards along each coordinate.

Section V. TARGET PRELAUNCH DIFFERENTIATORS

29. GENERAL

a. Theory and purpose. Velocity multiplied by time is equal to distance. Computation of the intercept point is based upon the distance a moving target will have traveled during a given time of flight. The target coordinate converter supplies the target present position data. It is the purpose of the target prelaunch differentiator to produce data proportional to the rate of change of the target present position in order to compute the intercept point. Symbols for these data are \dot{X}_P , \dot{Y}_P , and \dot{H}_P .

b. Components. The target prelaunch differentiator consists of three DC amplifiers, with capacitor inputs for differentiation, and resistor capacitor feedback networks for data smoothing. The amplifiers are labeled according to their output data, and are located on the right equipment frame in the computer amplifier cabinet. The inputs are X_T , Y_T , and H_T . The outputs are \dot{X}_P , \dot{Y}_P , and \dot{H}_P . The output scale factor is 12.5 millivolts per yard per second.

c. Operation. The target prelaunch differentiator is enabled by relay operation when the TARGET TRACKED signal is received. The functional operation is similar to that of the target steering differentiator and the missile differentiator to be studied later. The basic difference is in the data-smoothing characteristics. The target prelaunch differentiator uses 4-second, data-smoothing networks, but the target steering differentiator and missile differentiator uses 2-second, data smoothing networks.

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30. SIMPLIFIED FUNCTIONAL OPERATION

a. General. The basic principle of a differentiator which employs a DC amplifier and a data-smoothing network in the feedback circuit should be reviewed in TM 9-5000-13. Since the three differentiating circuits of the target prelaunch differentiator are identical, only the $+H_p$ differentiator will be considered (TM 9-5000-26, p 47).

b. Measurement of change of target position. When the position of the target is changing in altitude, there will be an output voltage whose amplitude is proportional to the rate of change of H_T . A positive present position of the target in the H-coordinate is represented by a negative voltage input to the differentiator. If the target is increasing in altitude at a uniform rate, the negative voltage representing the H position will be changing to a greater negative value, and the input voltage on the grid of the DC amplifier through the capacitor input will be negative. The DC amplifier will then have a positive output voltage whose magnitude is proportional to the H-component of target velocity (H). Since the H coordinate is increasing, the velocity is positive. Thus, there is a positive voltage representing a positive velocity, and the DC amplifier is labeled $+H_p$.

c. Data smoothing. The data-smoothing network is a resistor-capacitor network in the feedback circuit of the DC amplifier and is used to average the spurious rate voltages developed in the differentiator. The spurious rate voltages are a result of the uneven rate at which the TTR tracks a target, and the small voltage steps in the present position data are due to the granularity of the data potentiometers. The output data $+X_p$, $+Y_p$, and $+H_p$ are sent to the intercept point solver.

31. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, p 47)

Locate the functional schematic of the target prelaunch differentiator, which consists of the input networks and DC amplifiers labeled $+X_p$, $+Y_p$, and $+H_p$. An input labeled TEST is shown at terminal 4 of each of the networks. These inputs are voltages which represent test rates. They are applied through the prelaunch switch panel, and bypass the input differentiating circuit (TM 9-5000-26, p 23). The rate voltages are used for testing the prelaunch circuits of the computer. Refer to 61D8. Here it can be seen that ground is connected at terminals 4 while the prelaunch test relay, K25, is deenergized. K25 is energized by the COMPUTER CONDITION switch, S1 (TM 9-5000-26, p 106), during prelaunch tests. The enabling relays for the differentiators are located within the containers for the input networks (106B5). Here the differentiator enabling relays are found to be controlled by the target-tracked relay, K5, and the COMPUTER CONDITION switch, SIC. A contact of the fire relay, K7, is found to bypass the target-tracked relay, K5, and switch SIC. This contact is

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provided to keep the target differentiator enabled after FIRE so that any subsequent release of the target-tracked signal will not disable the computer. At 47B3, 47C3, and 47D3 are found dotted blocks labeled INDICATED ERROR AT BURST and referred to 5A3, 5B3, and 5C3. At these points target velocities are sent to the event recorder through contacts of deenergized burst enable relay K4 (109B8). Target velocities from the target prelaunch differentiator can be checked on the VELOCITY AND POSITION DIFFERENCE meters on the computer control panel when the VELOCITY AND POSITION DIFFERENCE control switch, S5, is in the PRELAUNCH position. Leads supplying output data to the intercept point solver are shown at 47B4, 47C4, and 47D9, terminals 577, 571, and 574 in the servo cabinet.

Section VI. THE INTERCEPT POINT SOLVER

32. GENERAL

a. Purpose. The purpose of the intercept point solver is to solve for the rectangular coordinates, X_I , Y_I , and H_I , or the point where the missile should meet the target. After the MISSILE TRACKED signal is received, the origin for the predicted intercept coordinates is the designated launcher. (Before this signal, the center of the launcher area is the origin for the intercept point coordinates.) The A_G servo computes the gyro azimuth, A_G . Because this azimuth is measured from the designated launcher to the predicted intercept point, the A_G servo must use intercept point coordinates (X_I , Y_I) with the designated launcher as the origin.

b. Components. The intercept point solver is used only in the prelaunch section of the computer. It is composed of three similar channels: one for X , one for Y , and one for the H computation. Each channel consists of a time-of-flight potentiometer, a dead time potentiometer, and an input network. The X_I and Y_I channels each contain one positive and one negative DC amplifier, but the H_I channel contains a negative amplifier only.

c. Location of components. The three time-of-flight potentiometers, T_C 10B, T_C 11B, and T_C 10A (47A13, 47B13, and 47C13), are located in the time-to-intercept servo assembly, in the servo cabinet. The dead-time potentiometers, T_D 3.25, T_D 2.75, and T_D 2.25, are located in the servo and timer assembly, in the servo cabinet. The five DC amplifiers and their respective input networks are located in the computer amplifier cabinet.

d. Inputs and outputs. The inputs to the intercept point solver from the target prelaunch differential are $+\dot{X}_p$, $+\dot{Y}_p$, and $+\dot{H}_p$ (representing target velocity components). The scale factor of these inputs is 12.5 mv/yard/sec. Inputs

$+X_T$, $+Y_T$, and $+H_T$ (representing target present position) come from the target coordinate converter with a scale factor of 1 mv/yd. Inputs $-X_L$, $-Y_L$, and $-H_L$ come from the launcher parallax unit with a scale factor of 1 mv/yd. The outputs, $+X_I$, $-X_I$, $+Y_I$, and $-Y_I$, go to the A_G servo. The $-X_I$ and $-Y_I$ outputs also go to the horizontal plotting board. The H_I output goes to the ballistic circuits and to the vertical plotting board. All outputs of the intercept point solver have a scale factor of 1 mv/yd.

33. MATHEMATICAL ANALYSIS (fig 7)

a. Computing coordinate X_I . The intercept point coordinates are measured from the launcher to the intercept point. For simplicity, figure 7 depicts a special situation for the solution of only the X_I coordinate by the intercept point solver. The formula for X_I is:

$$X_I = X_T - X_L + \dot{X}_p(t + t_d). \quad (14)$$

Launcher parallax X_L is the X-coordinate of the launcher position (from the target radar) in yards. By subtracting launcher parallax from the coordinates X_T of the present target location from the TTR, the launcher-to-target distance ($X_T - X_L$) is obtained. Target velocity \dot{X}_p , multiplied by the total time from FIRE until intercept ($t + t_d$), gives the distance the target will travel until it is intercepted by the missile.

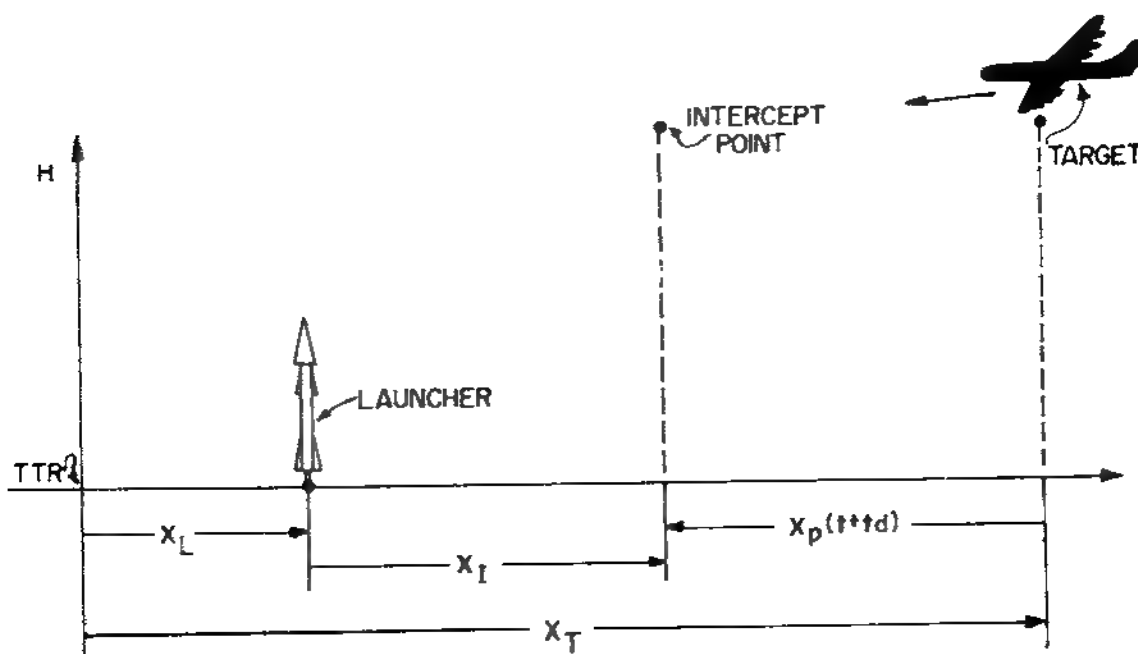


Figure 7. Computation of the intercept point coordinate, X_I .

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This distance, $\dot{X}_P(t + t_d)$, is added algebraically to the launcher-to-target distance ($X_T - X_L$), giving the coordinate X_I of the intercept point from the launcher.

b. Specific example. Any quantity in equation (14) can be positive or negative. The usual sign conventions apply: east, north, and up are positive; south, west, and down are negative. For example, consider a situation shown in figure 7. The launcher is 4,000 yards east of the TTR. The target is a plane presently located 60,000 yards east of the TTR and is moving westward toward the defended area with an X-component of velocity of 600 mph. At this instant the dial on the time-of-flight predictor reads 63 seconds. Following is a tabulation of given data:

$$\begin{aligned} X_T &= +60,000 \text{ yd} \\ X_L &= +4,000 \text{ yd} \\ \dot{X}_P &= -600 \text{ mph} \quad -300 \text{ yd/sec} \\ t &= 63 \text{ sec} \\ t_d &= 7 \text{ sec.} \end{aligned}$$

Substitute these values in equation (14) and solve for the X-component of the intercept point.

$$\begin{aligned} X_I &= +60,000 - (+4,000) + (-300)(63 + 7) \\ X_I &= +35,000 \text{ yd.} \end{aligned}$$

The predicted intercept point is located 35,000 yards east of the designated launcher. Bear in mind this solution is for one instant only ($t = 63 \text{ sec}$); in the computer the solution for intercept point (during prelaunch) is continuous.

c. Computing Y_I and H_I . Y_I and H_I are computed in exactly the same manner as X_I , and their equations are:

$$Y_I = Y_T - Y_L + \dot{Y}_P(t + t_d) \quad (15)$$

$$H_I = H_T - H_L + \dot{H}_P(t + t_d). \quad (16)$$

d. Dead time. Note that t_d , the dead time, is always 7 seconds during the prelaunch solution. This 7 seconds is the expected time interval between the pressing of the fire button (FIRE) and roll stabilization. This time is allocated

in the following manner: 2 seconds after FIRE for the mechanical settling of the caged roll amount gyro in the missile, 3 seconds for booster burnout and separation, and 2 seconds for the missile to accomplish roll stabilization, i.e., the pointing of the missile belly toward the predicted intercept point.

e. Time of flight. Time of flight, t , is assumed to be properly computed by the time-of-flight predictor. Note that t is measured from FIRE + 7 seconds until intercept. The dial on the front of the time servo drawer will read time of flight, t , during the prelaunch solution.

34. OPERATION OF INTERCEPT POINT SOLVER AFTER FIRE

At FIRE the A_G angle solution is fixed (frozen) and the missile is launched 2 seconds later. The prelaunch computer section cannot cease operation at this time because it is necessary to have a smooth time solution transition from the prelaunch solution to the steering time solution (if target velocity does not change) between FIRE and FIRE + 7 seconds. The dead time unit performs this function. The change in target position during this 7-second interval is compensated for by the decrease of dead time, t_d . For example, consider the preceding illustrative problem. At FIRE the computed intercept point component, X_I , was +35,000 yards. Now consider the same problem 6 seconds after FIRE ($t_d = 1$ sec) with no change in target velocity. The new target position coordinate (X_T) would be +58,200 yards. Use equation (14) which is also applicable after FIRE.

$$X_I = X_T - X_L + \dot{X}_P(t + t_d)$$

$$X_I = +58,200 - 4,000 - 300(63 + 1)$$

$$X_I = +35,000 \text{ yards.}$$

It can be seen that throughout the 7-second interval after FIRE, the predicted intercept point solution does not change if the target velocity is unchanged.

35. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, pp 47 and 49)

a. Inputs. The intercept point solver is shown on the right side of page 47 and on the left side of page 49. The inputs, \dot{X}_P , \dot{Y}_P , and \dot{H}_P , to the intercept point solver from the target prelaunch differentiators have a scale factor of 12.5 mv/yd/sec. The other inputs are $-X_L$, $-Y_L$, and H_L from the launcher parallax unit and the missile coordinate converter and $+X_T$, $+Y_T$, and $+H_T$ from the target coordinate converter with scale factors of 1 mv/yd.

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b. The Y-channel. Consider the Y-channel, one of the three channels in the intercept point solver. $-Y_I$ is a summing DC amplifier. $+\dot{Y}_P$ is multiplied by t and t_d at potentiometers T_C-10A and $T_D-2.75$, respectively. The top and bottom of T_C-10A represent 100 seconds and 0 seconds time of flight, respectively. One second is represented by $1/100$ of the potential across T_C-10A . The brush arm of this potentiometer is positioned by the time-of-flight predictor. To see the effect of T_C-10A and the $-Y_I$ amplifier on the scale factor, consider the following with the brush arm of T_C-10A positioned at 1 second:

$$\text{Input scale factor of } \dot{Y}_P \times \frac{1}{100} \text{ sec} \times \frac{R_B}{R_{in}} = \text{output scale factor}$$

$$12.5 \text{ mv/yd/sec} \times \frac{1}{100} \text{ sec} \times \frac{5}{.625} = 1 \text{ mv/yd.}$$

c. Influence of dead time. The top of $T_D-2.75$, the dead time potentiometer, represents 7 seconds. One second dead time is represented by one-seventh of the potential across $T_D-2.75$. To check the scale factor changes due to $T_D-2.75$ and the $-Y_I$ amplifier, consider the following:

$$\text{Input scale factor of } \dot{Y}_P \times \frac{1}{7} \text{ sec} \times \frac{25K}{44.6K} \times \frac{R_B}{R_{in}} = \text{output scale factor}$$

$$12.5 \text{ mv/yd/sec} \times \frac{1}{7} \text{ sec} \times \frac{25}{44.6} \times \frac{5}{5} = 1 \text{ mv/yd.}$$

d. Inversion. Inputs $-Y_L$ and $+Y_T$, with an input scale factor of 1 mv/yd, are only inverted by the $-Y_I$ amplifier since $R_B = R_{in}$ for these two inputs. Using the sign convention for the Nike I computer, the output of the $-Y_I$ amplifier is a negative voltage if the quantity Y_I is positive; that is, if the predicted intercept point is north of the selected launcher. Note that it is easy to obtain the formula for Y_I by examining the $-Y_I$ input network. Since $-Y_I$ is the output, $+Y_I$ must be the input because sign reversal occurs in the DC amplifier. Then the input $+Y_I$ is equal to $+\dot{Y}_P \cdot t + \dot{Y}_P \cdot t_d + Y_T - Y_L$, or $+Y_I = Y_T - Y_L + \dot{Y}_P(t + t_d)$. The output $-Y_I$ is inverted by the $+Y_I$ amplifier so that both $+Y_I$ and $-Y_I$ can be applied to potentiometer A_G-12 .

e. The X-and H channels. A discussion similar to the foregoing applies to the X-and H-channels except that the H-channel contains no $+H_I$ amplifier. The five DC amplifiers in the intercept point solver are zero set by semiprecision zero set group 8. The distribution of the outputs of the intercept point solver is as follows: $+X_I$ to A_G potentiometer A_G-13 ; $+Y_I$ to A_G potentiometer A_G-12 ; $-H_I$ to the ballistic elevation servo and the vertical plotting board; X_I and $-Y_I$ to the horizontal plotting board until missile away.

36. ILLUSTRATIVE PROBLEM

a. Problem. An enemy aircraft is approaching the battery position from a position 50,000 yards south and 50,000 yards west, and 42,000 feet above the TTR. The target is traveling northeast at 566 mph and is losing altitude at the rate of 900 feet per minute. The selected launcher is 2,000 yards west, 1,000 yards north, and 300 feet below the TTR. The time of-flight predictor dial reads 83 seconds. Compute X_I , Y_I , and H_I .

b. Tabulation of data. First, tabulate all data, then solve, using equations (14), (15), and (16):

X_T - 50,000 yd	Y_T - -50,000 yd	H_T +14,000 yd
X_L -2,000 yd	Y_L +1,000 yd	H_L -100 yd
\dot{X}_P +400 mph	\dot{Y}_P -200 yd/sec	\dot{H}_P -5 yd/sec
- +200 yd/sec		
t 83 sec	t 83 sec	t 83 sec
t_d = 7 sec	t_d 7 sec	t_d 7 sec

c. Solution.

$$(1) X_I = X_T - X_L + \dot{X}_P(t + t_d) = -50,000 + 2,000 + 200(83 + 7) = -30,000 \text{ yd.}$$

$$(2) Y_I = Y_T - X_L + \dot{Y}_P(t + t_d) = -50,000 - 1,000 + 200(83 + 7) = -33,000 \text{ yd.}$$

$$(3) H_I = H_T - H_L + \dot{H}_P(t + t_d) = 14,000 + 100 - 5(83 + 7) = +13,650 \text{ yd.}$$

The predicted intercept point is 30,000 yards west, 33,000 yards south, and 13,650 yards above the designated launcher.

Section VII. DEAD-TIME UNIT

37. GENERAL

a. Purpose. One purpose of the dead-time unit is to provide for a smooth transition between the time-of-flight predictor time solution and the time solution of the time to-intercept servo. Another purpose is to reject the missile at FIRE + 5 seconds if it has not left the launcher.

b. Sequence. The solution for time in the Nike I computer is performed by the following units for the intervals indicated:

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10 April 1956

INTERVAL

UNIT SOLVING FOR TIME

PRELAUNCH

TARGET TRACKED to FIRE	Time-of-flight predictor (t changing); dead-time unit (t_d constant at 7 seconds).
FIRE to FIRE + 7 seconds	Time-of-flight predictor (t constant); dead-time unit (t_d decreases from 7 seconds to zero).
At FIRE + 7 seconds	Prelaunch time components cannot change the time solution. This instant ordinarily coincides with roll stabilization and MA + 4 seconds.

STEERING

MA + 4 seconds to ON TRAJECTORY	Time is decreased at 1 second per second by bias circuit in time-to-intercept servo.
ON TRAJECTORY to $t = 0.25$ second	Time solution performed by time to intercept servo.
$t = 0.25$ second to $t = 0$ second	Time is decreased at 1 second per second by bias circuit in time-to intercept servo.

The above data indicates that the dead-time unit controls the time solution from FIRE to FIRE + 7 seconds. The dead-time unit, in effect, freezes the intercept point solution (X_I , Y_I , and H_I) for 7 seconds if the target velocity does not change. If the target velocity does not change, the time of-flight servo will not change its solution for t and a smooth transition to control by the time-to-intercept servo will be effected.

c. Dead-time mechanism. The dead-time unit is located in the right side of the servo and timer assembly in the servo cabinet. The mechanical schematic of the dead time unit is shown on TM 9-5000-26, page 53. The dead-time motor, B3, is a split phase synchronous motor which operates at 8,000 rpm (.0075 sec t_d , rev). An electromagnetic clutch controls the application of mechanical power from the dead-time motor to the gearing. This clutch is engaged at FIRE. A dial indicating the dead time is available in the servo cabinet. A friction clutch prevents the dials and gearing from turning after the magnetic clutch has been disengaged. The dead-time potentiometers contained in the GA-10035 assembly are used by the intercept point solver. Microswitches S1 and S2 control zero reset and the missile reject action, respectively.

38. DETAILED FUNCTIONAL OPERATION

The circuitry of the dead-time unit is shown in figure 8, and figure 9 summarizes the sequence of its operation. When K6, the target differentiator enable relay (TDE), is energized, it causes the dead-time motor, B3, to start; this motor will then run continuously throughout the remainder of the engagement. Motor B3 is a split-phase synchronous motor (the phase-splitting network is shown at 53D7) which uses phase C (MTR X). When the FIRE button is pressed, relay ground is connected to the bottom of clutch coil L2 through contacts 9 and 2 of energized fire relay K3 and contacts 8 and 12 of deenergized MAL relay K5. When the coil of L2 is energized, the clutch is engaged and motor B3 turns the gearing connected to the dead time potentiometers (T_D 3.25, T_D 2.75, and T_D 2.25) the zero reset and F+5 cams, and the dead-time dial. Approximately 0.3 second after FIRE, the zero reset cam closes microswitch S1, placing a second relay ground connection to the bottom of clutch coil L2 (through contacts 3 and 1 of S1). Approximately 3 seconds after FIRE, missile away is detected and MAL relay K5 is energized. This action removes the first relay ground connection from coil L2. Five seconds after FIRE (with the t_d dial reading 2.0 seconds), the F+5 cam closes microswitch S2 which energizes the reject relay of the designated launcher if MISSILE AWAY has not been received. This action prevents firing if the missile is still in the launcher. Seven seconds after FIRE, the dead time potentiometer brushes have revolved 330° , from their / second position to the zero second position. The dead time unit, however, continues to revolve the remaining 30° , during which time the dead-time potentiometer brushes are at ground potential. Approximately 7.637 seconds after FIRE (360° of revolution of the T_D potentiometer brushes), the zero reset cam opens microswitch S1 which removes the second relay ground connection from the bottom of coil L2. This deenergizes coil L2, disengaging the clutch, which completes the action called zero reset. After zero reset, the dial of the dead time unit should read 7.0 seconds and the dead time unit is positioned as shown in figure 8; however, motor B3 continues to run.

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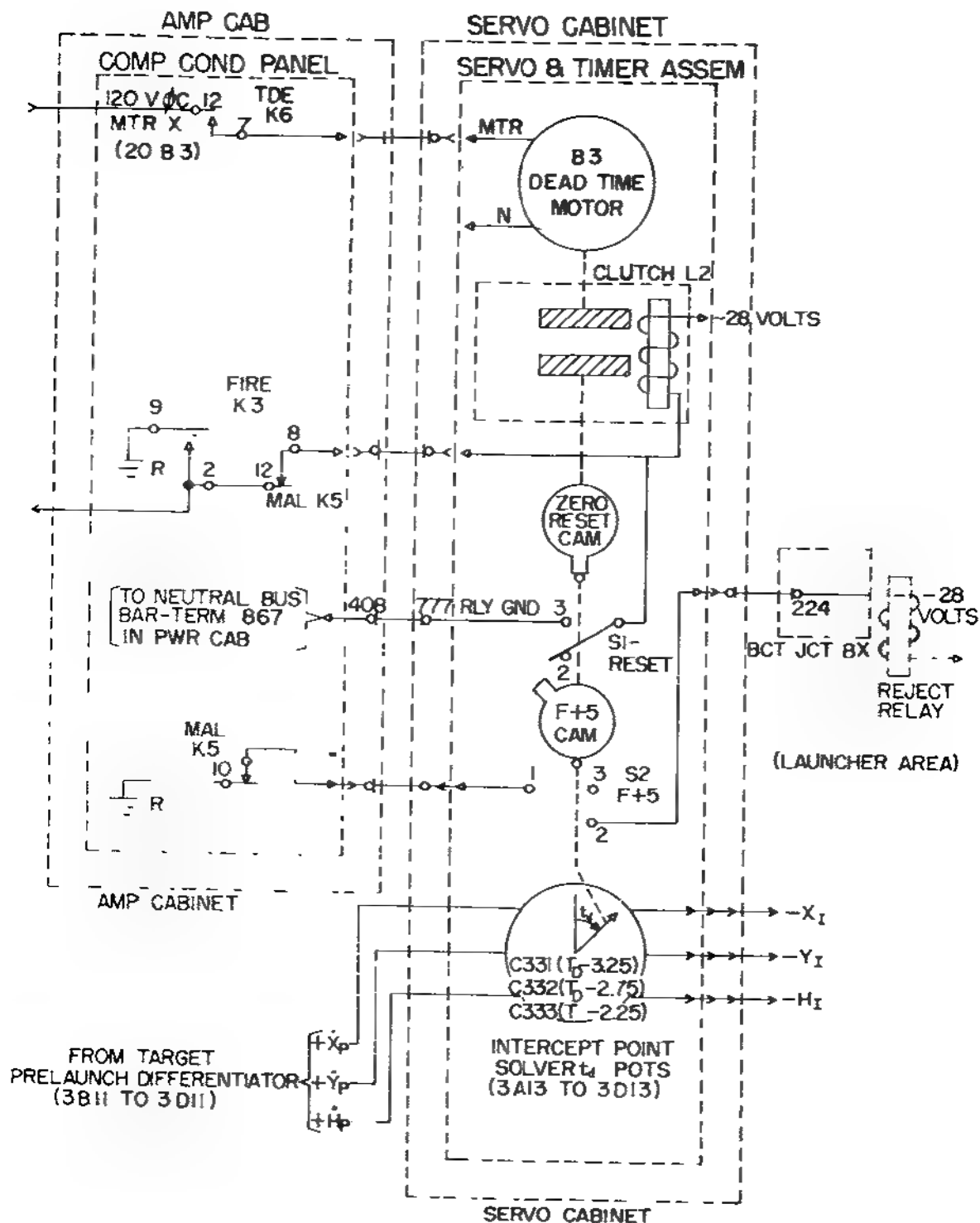


Figure 8. Functional schematic of dead-time unit in reset position (t_d dial reads 7.0 sec).

TIME	OPERATION
TDE	Dead-time motor B3 starts when K6, TDE relay, energizes.
FIRE	Clutch coil of L2 is energized through J4-K. Clutch plates close. Brush arms on intercept point potentiometers turn from 7 seconds toward 0 seconds.
FIRE + 0.3 second	S1 is closed by zero reset cam, placing a second ground at the bottom of coil L2.
MA	K5 MAL relay energizes, removing ground at J4-K.
FIRE + 5 seconds	(The t_d dial reads 2.0 seconds.) F+5 cam closes S2, which will energize reject relay if the missile has not left the launcher, i.e., MAL relay K5 has not energized.
FIRE + 7 seconds	(The t_d dial reads 0 seconds.) Brush arm of intercept point solver potentiometers $T_D-3.25$, $T_D-2.75$, and $T_D-2.25$ reach ground potential (330° of revolution). During remaining 30° of travel (0.637 second) brush arms are an open circuit.
FIRE + 7.637 seconds	(The t_d dial again reads 7.0 seconds.) Zero reset cam opens S1, deenergizing clutch coil of L2, and resetting dead-time unit at dial reading of 7.0 seconds. (Unit in fig 8 is shown in reset condition.)

Figure 9. Timing sequence of the dead-time unit.

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Section VIII. BALLISTIC CIRCUITS

39. GENERAL

a. Purpose. To determine the ballistic functions of the missile during the prelaunch phase, a special circuit is used which can represent these characteristics of the missile as a function of time. It is, in a sense, a ballistic table to which the computer can refer.

b. Components. These tables are composed physically of a DC amplifier and its input network, a modulator, a low-power servoamplifier, a servomotor generator and associated gearing, a feedback device for geometric gain control, three potentiometers, and several resistive networks. The B-amplifier and input network are located on the frame of the right amplifier cabinet. The B-modulator shares a chassis with the A_G modulator. It is located in the rear bay of the right amplifier cabinet, next to the B low-power servoamplifier. A ballistic resistor panel contains most of the resistive networks mentioned. TM 9-5000-26, page 7, shows this panel at the top of the servo cabinet and the servo and timer assembly at the bottom. The servo and timer assembly mounts the mechanical parts of the A_G and B servos, and t_d unit. The portion relating to the ballistic circuits is in the center; that is, the potentiometers, servomotor generator, and gearing.

c. Inputs and outputs. The quantity, $-H_I$, is supplied as one input voltage from the intercept point solver with a scale factor of 1 mv/yd. The t -servo provides a $+t$ voltage and positions mechanically four potentiometer brush arms. From these inputs, voltages are generated which position the ballistic servo system through a normal computer servo channel. The ballistic circuits provide two output signals to the t_{pl} input network, $+R_B$ and $+D_B \cos B$, which together are analogous to a ground range to the intercept point.

40. MATHEMATICAL ANALYSIS

a. Constant time circle. When this system was developed in the laboratory, it was found that the flight of the missile could be related to constant time circles. Some of these are illustrated in figure 10. If a missile were launched from the origin of this coordinate system, it would require 40 seconds to reach any point on the 40-second curve. Thus, it would require the same time, 40 seconds, to reach a target at a 22,000-yard horizontal range and a 57,000-foot altitude so as to reach a target at a 25,000 yard horizontal range and a 15,000-foot altitude. These curves can be approximated by circles called constant time circles, each of a different radius. The center of these circles is identified by labeled points on the locus. Because there is but one constant time circle for

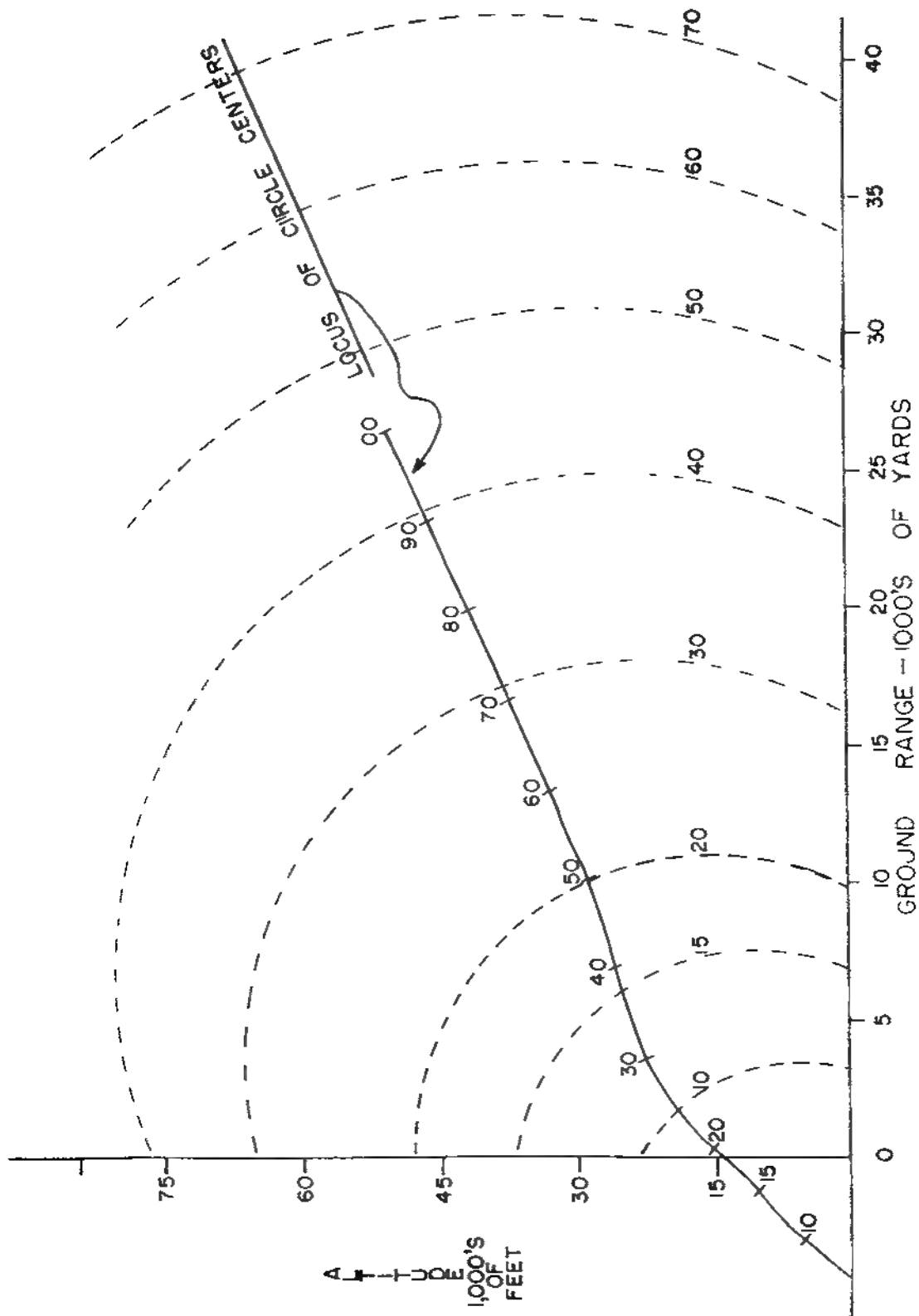


Figure 10. Constant time circles.

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any one point on the locus, and because each time circle has a different radius, it is possible to plot the coordinates of the circle centers and radii as functions of time.

b. Ballistic elevation angle B. In figure 11, the circle center is represented by the coordinates, R_B and H_B ; the radius by D_B . Any point in the gyro azimuth plane, for example, can be designated by using H_I , R_I , D_B , and the angle at which the radius, D_B , must be positioned from the horizontal plane. This angle is the ballistic elevation angle B . Angle B is determined by the ballistic elevation B servo. Angle B is needed only to obtain a correct value of time of flight.

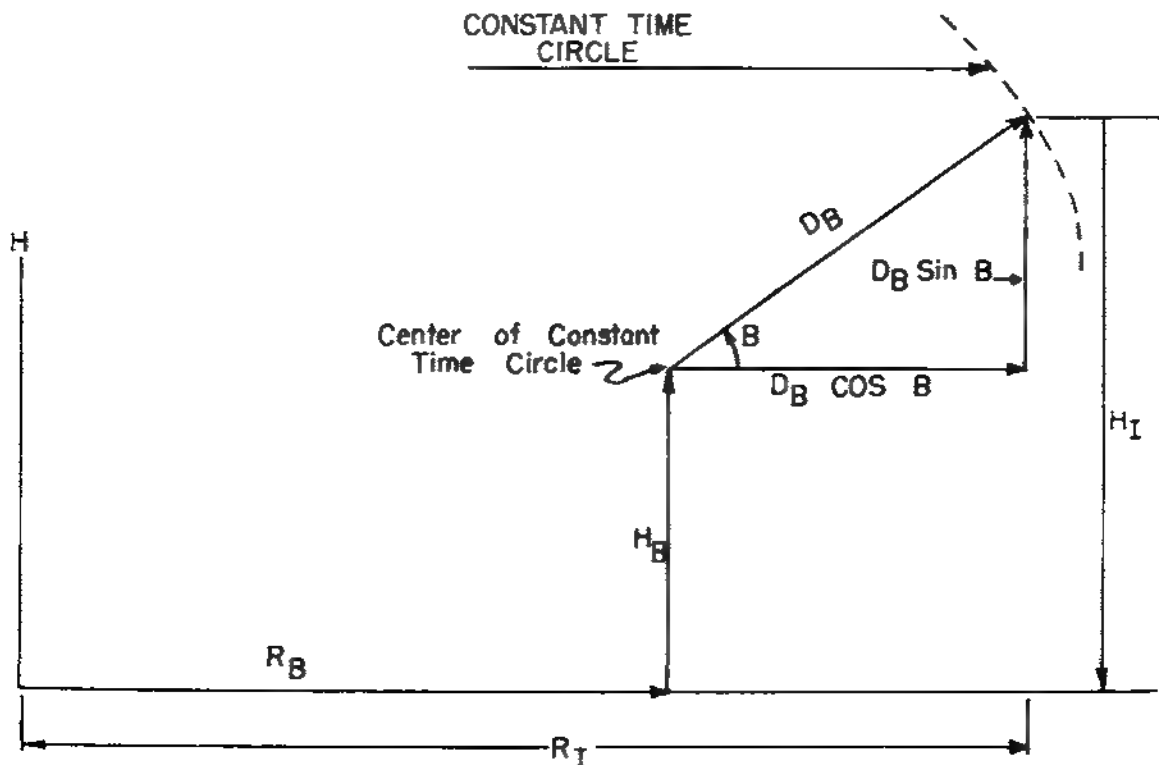


Figure 11. Calculation of ballistic elevation angle.

c. The time solution. The time servo compares the computed ground range to the intercept point from the gyro azimuth servo ($-R_I$) with the empirical ground range from the ballistic circuits ($R_B + D_B \cos B$) in the equation,

$$-R_I + R_B + D_B \cos B = 0. \quad (17)$$

This solution presumes a correct value of angle B , which must be determined. $-X_I$ and $-Y_I$ are used in the A_G servo to obtain $-R_I$ for use in the t servo, so B must be found by using other parameters.

d. Ballistic height. In figure 11, the ballistic height of the intercept point is composed of the parameter, H_B , and the projection of the radius, D_B , on the perpendicular from the intercept point to the horizontal plane. The predicted height of intercept is

$$+H_I = H_T - H_L + \dot{H}_p(t + t_d). \quad (18)$$

The missile and the target should coincide in the vertical plane at burst, so the B-servo uses the equation,

$$H_I + H_B + D_B \sin B = 0, \quad (19)$$

to obtain a solution for angle B. H_B and D_B are generated in the ballistic circuits. $-H_I$ is available from the intercept point solver. This leaves $\sin B$ the only quantity of equation (19) to be controlled by the B-servo. $\sin B$ may be of either polarity, positive if angle B is above the horizontal, negative if below.

41. SIMPLIFIED FUNCTIONAL OPERATION

a. Servo operation. The functional block diagram of a simple closed loop control system is drawn in dashed lines in figure 12. The controlled variable is compared with the reference inputs by a comparator. The error existing between the input and output is used to energize elements in the controller, which control the output in an effort to eliminate the error. As may be seen in figure 12, the B servo conforms to a basic closed loop control system. The reference input (H_I) from the intercept point solver is applied to the comparator (B amplifier). The second reference ($+H_B$ and $+D_B$) is generated in other parts of the ballistic circuits. H_B is fed directly to the comparator, but D_B is modified by the feedback element (a ballistic sine potentiometer card) before being used in the comparator. If correct values are assumed for t and A_G , then D_B is the only input to be altered by feedback. Since $-H_I$ is a negative voltage, $+H_B + D_B \sin B$ must ordinarily be a positive voltage in order that equation (19) be used by this servo. When the two reference inputs are of equal magnitude, no error exists and equation (19) is satisfied.

b. Controller operation. Before reaching a solution, the B amplifier applies the error (d-c voltage) to the modulator. Here it modulates a 400-cps, a-c voltage in both phase and amplitude to control the motor. This a-c voltage is raised in power level by the low-power servoamplifier and applied to the control winding of the servomotor generator. Since the generator is directly attached to the motor armature, it has as its output a 400-cps voltage that is directly proportional to the motor speed. This voltage, 180° out of phase with the voltage going to the servoamplifier from the modulator, is mixed with the a-c drive voltage as negative feedback, and is used to damp oscillations of the

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drive elements of the servo. The controlled variable B is a mechanical shaft position of the brush arms of five B-potentiometers. One of these potentiometer cards is used as the feedback element.

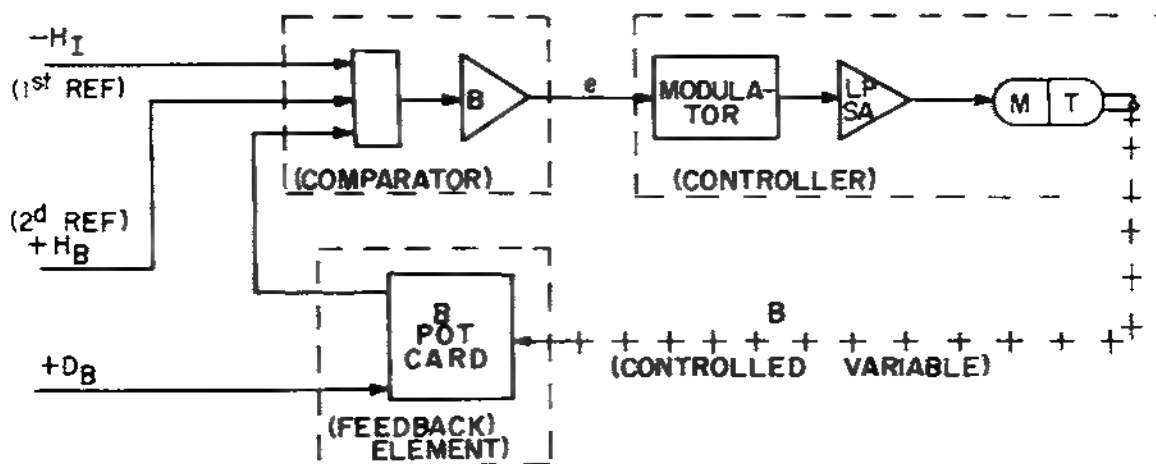


Figure 12. The B-servo as a basic closed loop control system.

42. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26. pp 49 and 52)

a. Assumption. In the discussion of the ballistic servo system it is assumed the t and A_G servos are set for a correct solution, and the system is required to arrive at a solution for B only.

b. Inputs to the B-amplifier. The three inputs to the B-amplifier may be seen at 52B3. $-H_I$ is determined in the same manner as $-X_I$ and Y_I by the intercept point solver and is a fixed quantity insofar as the B-servo is concerned. The first reference, $-H_I$, is a negative voltage brought into terminal 3 of the B-amplifier input network.

c. Ballistic functions. In figure 10, the empirical $+H_B$ is seen to be an almost linear function of time. To generate a positive voltage exactly analogous to this parameter, a voltage divider and a loaded, linear, coarse-time potentiometer card are used between +250 volts and ground. The circuit is shown at 52B1. Test terminal 580 for time card T_C-8B is located in the rear of the servo cabinet; voltage measured at this point should be the same as at terminal 5 of the B-network, which is equal to $-H_B$. As may be seen in figure 10, D_B lengthens with an increase in time of flight, but is not quite linear.

d. Polarity of $\sin B$. $\sin B$ may be either positive or negative. If the intercept point is above the horizontal plane containing the constant time circle

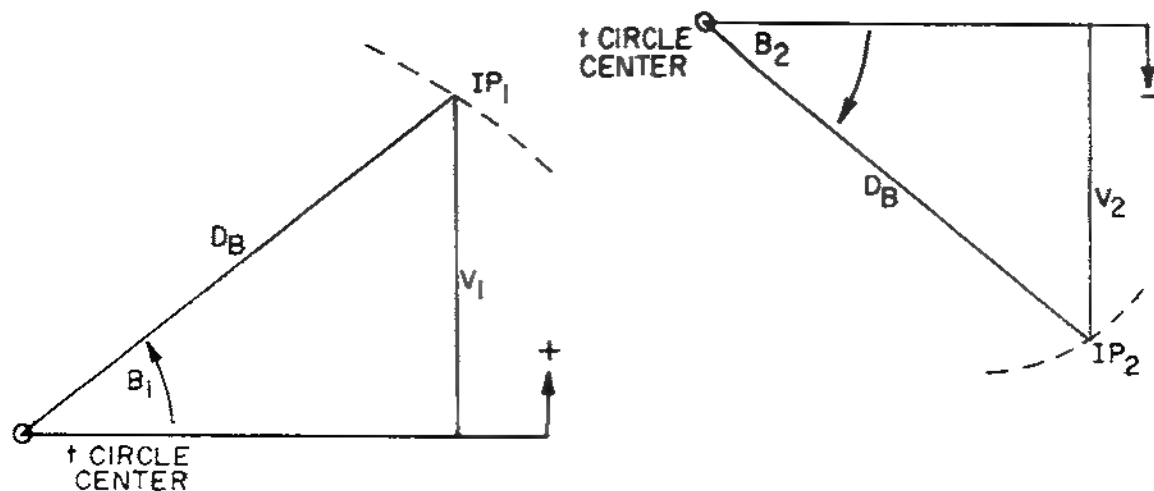


Figure 13. Positive and negative values of $\sin B$.

center, as for angle B_1 in figure 13,

$$\sin B = +V_1/D_B, \text{ a positive quantity.}$$

If the intercept point is below the horizontal plane containing the constant time circle center, as for angle B_2 ,

$$\sin B = -V_2/D_B, \text{ a negative quantity.}$$

Since D_B is intrinsically a positive quantity, two supply voltages and two time cards are used to generate $D_B \sin B$ of proper polarity (49D4).

e. Time cards. The two coarse time cards are linear and identical. They are connected to the loading resistors, R7 and R8, to give a nonlinear output, D_B . $T_C - 6A$, between +250 volts and ground, yields $+D_B$; $T_C - 6B$, between -250 volts and ground, yields $-D_B$. Both $+D_B$ and $-D_B$ feed a B-potentiometer card (B-5.25). This B card is wound as a 360°, sine-cosine function card. A brush arm delivers to terminal 4 of the B-input network a voltage ($+D_B \sin B$) of zero when $B = 0^\circ$, +32 volts when $B = 90^\circ$, and -32 volts when $B = 270^\circ$. It is seen now that of the voltages representing equation (19), $-H_I$ is always negative, $+H_B$ is always positive, and $+D_B \sin B$ may be of either polarity. The brush arm of B-5.25 is positioned by the B-servomotor. In this manner the second reference voltage, D_B , is modified by the feedback from the B-servo. All the inputs are terminated in 1/2-megohm resistors.

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f. Error voltage. The unbalanced portion of the input is the actuating error. As a d-c voltage, it passes through the B-amplifier to the B-modulator (p 52 of TM 9-5000-26). This error voltage is used as the signal input to the modulator. Phase and amplitude of the modulator output are controlled respectively by the polarity and magnitude of the d-c input. The low-power servoamplifier raises the power level of the 400 cps voltage and transmits it through the contacts of the steer relay, K37, to the control windings of the 2-phase induction motor. When the steer relay is energized at missile away + 4 seconds, driving voltage is removed from the motor, and the angle B becomes fixed. The outputs of the ballistic circuits are three voltages, $+R_{B1}$, R_{B2} , and $+D_B \cos B$, which represent $+R_1$. This is used in the time-of-flight predictor discussed in section XI. $+D_B \cos B$ coming from the other potentiometer arm of B-5.25 is always a positive voltage. $+R_B$ itself is not used in the ballistic circuits. The time of-flight predictor uses $+R_B$ to determine the proper time of flight, as indicated in equation (17).

g. R_B and its functions. In figure 10, R_B is almost a linear function of time. When t is zero, R_B is equal to -6,130 yards; or when R_B is zero, t is 18.74 seconds. The computer generates R_B in two parts: one is the constant factor first noted, and the other is a function of time. The first is represented by the negative voltage from the voltage divider between -250 volts and ground at 49C5.

Within the 1 percent tolerance of these resistors the voltage delivered to terminal 6 of the t_{p1} network (-6.130v) represents -6,130 yards. The second factor is determined from the fact that when R_B is zero, t is 18.74.

$$R_B = -6,130 + 18.74k, \quad (20)$$

that is, $k = (R_B + 6,130)/18.74$ or $k = 327.1$ when R_B is zero, then

$$R_B = -6,130 + 327.1t. \quad (21)$$

By utilizing the $+t$ voltage (1 volt equals 1 second) to supply the other voltage divider at 49C5, the quantity, R_B , is completed.

h. Ballistic potentiometer cards. There are three ballistic potentiometer cards. Two are used in the B-servo: B-5.25 as a feedback element, and B-4.75 as a geometric gain control (par 43). The third card, B-4.25, is discussed as a geometric gain control for the A_G amplifier in section IX.

43. GEOMETRIC GAIN CONTROL (TM 9-5000-26, p 52)

a. Feedback loops. There are three auxiliary feedback loops in the B servo.

- (1) The first is the normal output limiter, connected directly from output to input of the B-amplifier (TM 9-5000-26, p 52).

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- (2) The second is the speed feedback connected from the generator to the modulator.
- (3) The third is the geometric gain control from output to input network of the B amplifier.

b. Gain control circuit. This circuit contains a coarse-time card, T_C-8A , and a B cosine card, B-4.75. Consider the two angles, B, for the given constant time circle center of figure 14. B_1 is greater than B_2 . A change in B_1 yields an increase of Δ_1 in $D_B \sin B$. A like change in angle B_2 yields an increase of Δ_2 in $D_B \sin B$. Δ_2 is greater than Δ_1 . If constant negative feedback were used, a small change of B near 90° would cause less response from the servo than a similar change near 0° . In other words, the sensitivity of the B servo would decrease as the angle, B, increased. Gain increases as negative feedback decreases in such a circuit, so that decreasing the feedback as angle B increases causes the B amplifier to have a constant sensitivity. The rate of change of equation (19) as B changes is $-D_B \cos B$, and the potentiometer card, B-4.75 introduces the function, $-D_B \cos B$, in the feedback path to increase the gain of the B amplifier at large values of B.

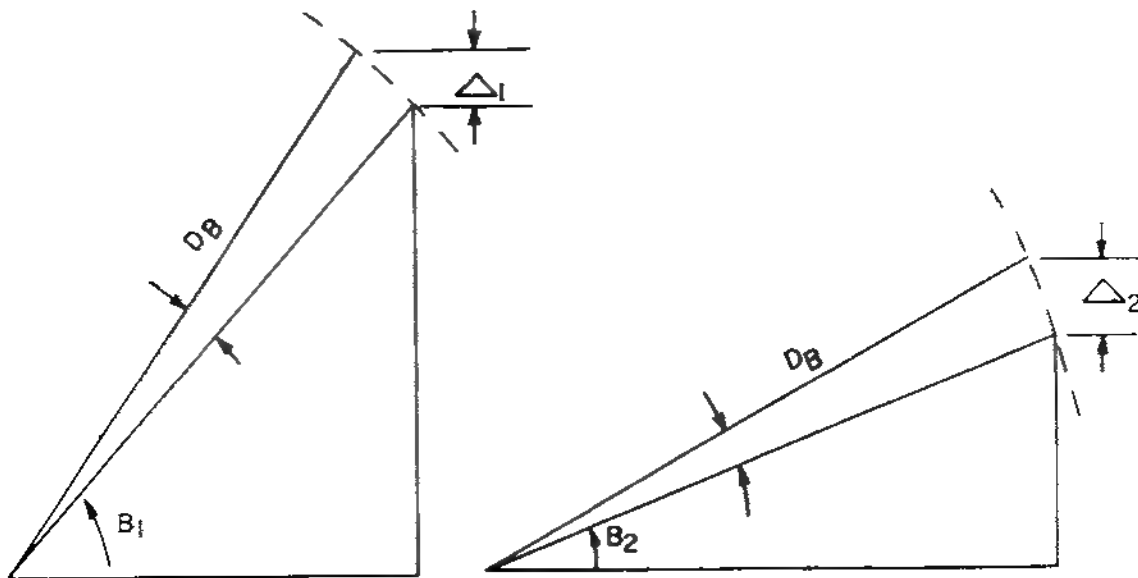


Figure 14. Geometric effects of different angles B.

c. Effect of time. Consider the effect of time on the ballistic triangle, at a constant angle B. A small change in t for long times of flight produces a change, Δ_1 , in $D_B \sin B$ (fig 15). A similar change in t for a short time of

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flight produces a larger change, Δ_2 , in $D_B \sin B$. Δ_2 is greater than Δ_1 because D_B , which is the radius of the constant time circle, does not change linearly as time of flight varies. Time cards T_C -6A and T_C -6B are loaded so that their outputs are curved functions of t that approximate $+D_B$ and $-D_B$. $D_B \sin B$ is one of the inputs that drive the B-servo. The change of $D_B \sin B$ voltage, for equal changes in t , will not be the same at short times of flight as it is at long times of flight. Time card T_C 8A in the feedback loop of the B-servo will compensate for the nonlinearity of the $D_B \sin B$ input and will maintain constant sensitivity for the B-amplifier for equal changes in t at both long and short times of flight.

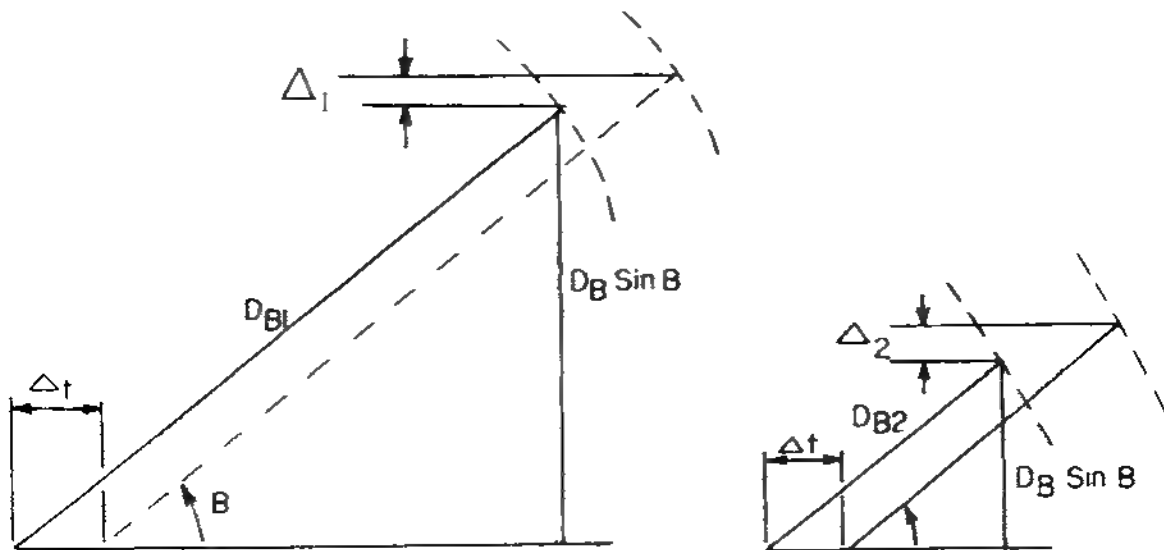


Figure 15. Geometric effect of different times of flight.

44. MECHANICAL OPERATION (TM 9-5000-26, pp 53 and 54)

The circuit diagram for the ballistic section of the servo and timer assembly may be seen in TM 9-5000-26, page 53, at the center of the page. The potentiometer cards described in paragraph 42 above are illustrated and the plug connectors are labeled. The servomotor generator, MG-2, connections and gear reduction box are seen at the bottom. The gear ratio is 1,200:1. Top speed of the motor is 9,000 rpm, or 850 mils per second. Resistor R5 is a potentiometer used to adjust the phase of the Tach X supply to the generator. In TM 9-5000-26, page 54, is shown the mechanical connections of the servo and timer assembly. MG-2 is at the lower left center of the page. The gear train has two gears, one on top of the other, spring loaded to provide tight coupling into the train. The coarse dial is driven at a rate of 400 mils per revolution. The fine dial is driven at the same rate by planetary gears between the coarse

and fine dials. Provision is made to zero set the potentiometer cards by the shaft coupling and the manual drive.

Section IX. GYRO AZIMUTH SERVO

45. GENERAL

a. Purpose. One purpose of the gyro azimuth servo is to solve for the proper azimuth (A_G) to the predicted intercept point. A second purpose is to solve for the ground range to the intercept point ($-R_I$) which is sent to the time-of-flight predictor.

b. Components. The A_G servo consists of two sine-cosine potentiometers, a DC amplifier, a modulator, a low-power servoamplifier, a servomotor generator, and a geometric gain control. The inputs come from the X- and Y-channels of the intercept point solver. One output is a shaft motion that positions the A_G resolver in the gyro azimuth servo system to transmit the gyro azimuth data to the launcher area. A second output, $-R_I$, goes from the sine cosine potentiometers to the time-of-flight predictor. The scale factor in this servo is 1 mv/yard.

c. Geometric gain control. The servo system contains a circuit called a geometric gain control which causes the A_G servo system to have the same response when intercept points are at short ranges as at long ranges. Without the geometric gain control, the servo system would be less sensitive and would take longer to solve for the A_G angle at shorter ranges. This is undesirable since at short range, time is at a premium, A_G changes faster, and the A_G solution must be more accurate than at greater ranges. Geometric gain control in the A_G servo consists of increasing the gain of the A_G DC amplifier as the ground range to the intercept point decreases.

46. MATHEMATICAL ANALYSIS

a. The gyro azimuth angle. The A_G servo solves for the gyro azimuth (A_G) of the predicted intercept point by comparing elements of the triangle shown in figure 16. The gyro azimuth (A_G) is the clockwise angle (measured in mils at the designated launcher) from north (Y-axis) to the predicted intercept point. For example, a gyro azimuth of 5,600 mils indicates that the predicted intercept point is exactly northwest of the launcher designated to fire.

b. Gyro azimuth solution. The right triangle whose legs are X_I and Y_I , defines the A_G angle. This can also be stated as follows: The A_G angle is the angle the tangent of which is X_I divided by Y_I ; or

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$$\tan A_G = \frac{X_I}{Y_I} \quad (22)$$

The tangent of any angle is its sine divided by its cosine. Therefore,

$$\tan A_G = \frac{\sin A_G}{\cos A_G} \quad (23)$$

By equating the expressions for $\tan A_G$ given in equations (22) and (23) equation (24) is obtained:

$$\frac{X_I}{Y_I} = \frac{\sin A_G}{\cos A_G} \quad (24)$$

Cross multiplying in equation (24), it is found that

$$Y_I \sin A_G = X_I \cos A_G \quad (25)$$

or

$$Y_I \sin A_G - X_I \cos A_G = 0 \quad (26)$$

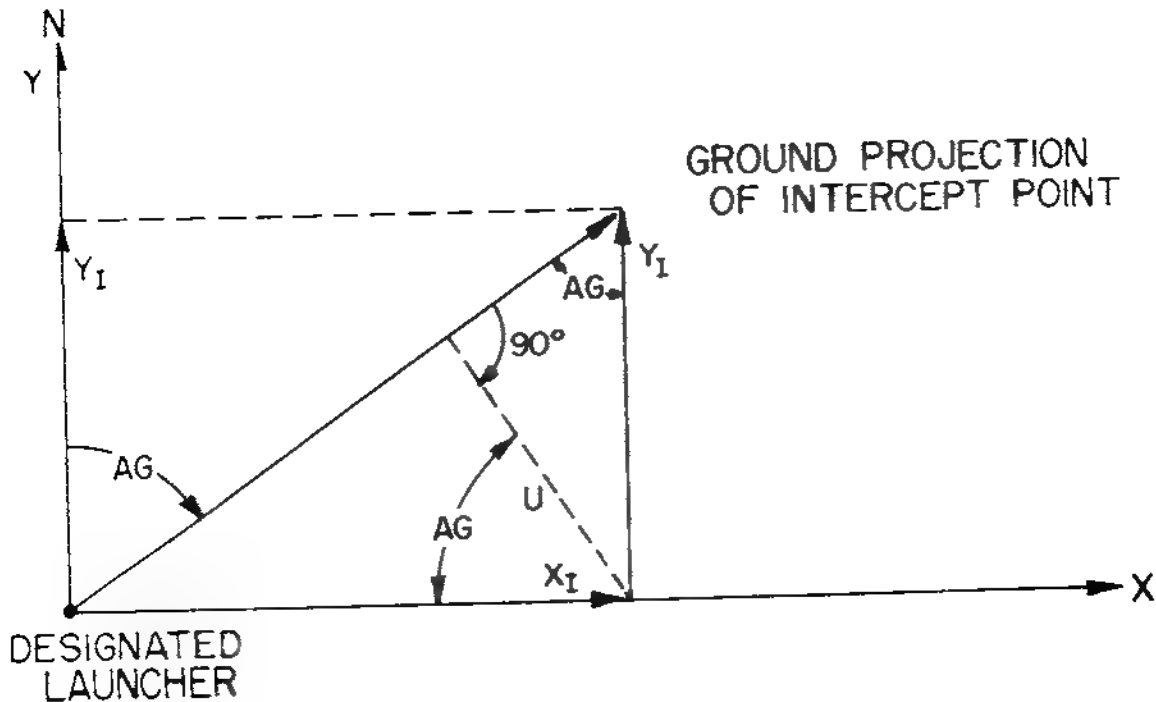


Figure 16. Trigonometry involved in A_G solution.

Equation (26) is the mathematical expression used by the A_G servo to determine the gyro azimuth. For any given X_I and Y_I , the A_G solution is correct when equation (26) is satisfied, that is, when the difference between $Y_I \sin A_G$ and $X_I \cos A_G$ is zero.

c. Alternate gyro azimuth solution. Equation (25) can also be obtained by dropping a perpendicular line (U) from the right angle to the hypotenuse as shown in figure 16. Two smaller triangles are thus created. The small left triangle yields the relationship: $U = X_I \cos A_G$. The right small triangle gives $U = Y_I \sin A_G$. By equating the two expressions for line U, equation (25) above is obtained.

47. SIMPLIFIED FUNCTIONAL OPERATION

a. General. The functional block diagram of a basic servo (closed loop control) system is shown in TM 9-5000-26, page 20. The controlled variable (output) is compared with the reference inputs by an error measuring means (comparator). The existing error between the input and output is used to actuate elements which control the output variable to eliminate the existing error. In most servos the reference inputs are constantly changing so that an actuating error always exists in order to keep the output following the inputs as closely as possible. The gyro azimuth (A_G) servo system conforms generally to the basic servo system given in TM 9-5000-26, page 20. The elements of the A_G servo shown in figure 17 are arranged in the configuration of the basic servo.

b. Inputs and outputs. The reference inputs ($+X_I$, $+Y_I$) from the intercept point solver are applied to sine-cosine potentiometers (feedback elements) whose brush arms are positioned by the controlled variable. The outputs of the feedback elements are $-X_I \cos A_G$ and $+Y_I \sin A_G$, which are compared in the A_G DC amplifier (comparator). Note that each of the inputs to the A_G amplifier ($+Y_I \sin A_G$, for example) is the product of a reference input ($+Y_I$) and a feedback function ($\sin A_G$). When the two inputs to the A_G amplifier are equal and opposite the equation, $Y_I \sin A_G - X_I \cos A_G$, is satisfied, the actuating error (d-c voltage) reaches zero, and the proper solution for A_G has been obtained.

c. Controller operation. The d c input (actuating error) to the modulator is used to control the phase and amplitude of a 400-cycle a c voltage to properly control the servomotor generator. This a-c output is amplified by a low power servoamplifier and is then applied to the control winding of a 2-phase induction motor. The generator is built on the same shaft as the motor armature so that its output is a 400 cycle voltage with an amplitude directly proportional to motor speed and a phase 180° from that of the voltage input to the low power servo amplifier. Thus, negative feedback is used to provide what is known as speed feedback damping. This prevents hunting of the servo system. The output

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(controlled variable) is a mechanical shaft motion which positions the A_G resolver. The A_G resolver transmits A_G data to the launcher area. The feed-back is a mechanical shaft motion which positions the A_G potentiometer brushes.

48. DETAILED FUNCTIONAL OPERATIONS (TM 9-5000-26, pp 49, 53, and 54)

a. References. The mechanical schematic of the A_G servo assembly (motor, gears, and dial) is in TM 9-5000-26, page 54, on the left side of the page. This assembly is located in the servo and timer assembly in the servo cabinet. The electrical schematic of the servo assembly appears in TM 9-5000-26, page 53.

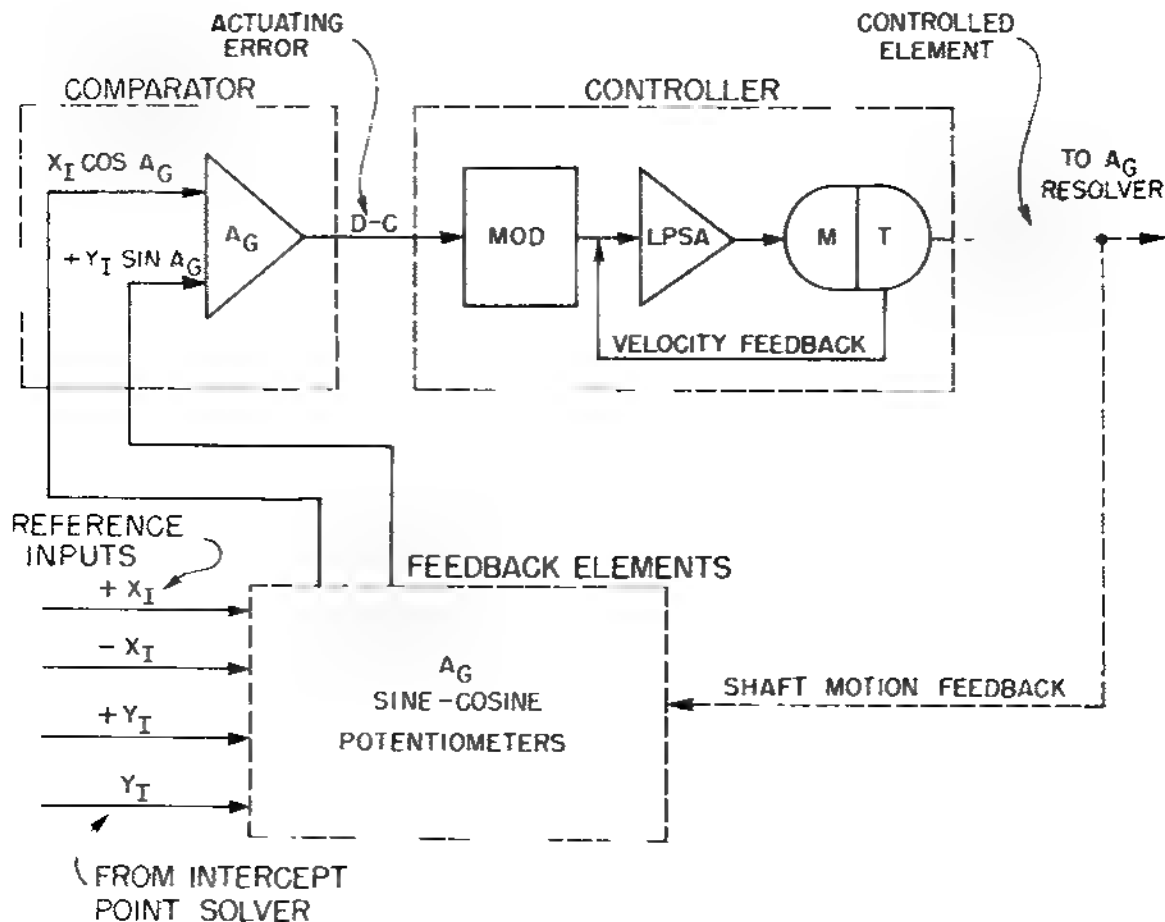
b. The A_G potentiometers. The eight A_G potentiometers, and the units in which they are used, are as follows:

- (1) A_G -12 and A_G -13 in the A_G servo.
- (2) A_G 10 and A_G -11 in the steering error converter.
- (3) A_G -8 and A_G 9 in the missile rate converter.
- (4) A_G 6 and A_G -7 in the initial turn section of the computer.

c. Motors and synchros. The servomotor generator is in the lower left corner of the page. The motor drives the brush arms of the eight A_G potentiometers, the rotor of synchro transmitter B2, and the rotor of resolver B1. Synchro transmitter B2 is used with a synchro receiver in the tactical control panel in the battery control console. This synchro receiver positions the dial of the GYRO AZIMUTH meter in the lower right corner of the panel. The resolver, B1, sends A_G data to the launcher area through lines connected to J3-K, J3-L, and J3 J.

d. A_G transmission system and brake. Briefly examine the associated components of the A_G transmission system in section X of TM 9-5000-26. Note also the A_G brake coil, L1. When the FIRE button is pressed, relay ground is applied at J3-F, energizing coil L1 which locks the A_G servo gearing. Two seconds after this action, the missile lifts off. The 2-second interval allows for the mechanical settling of the roll-amount gyroscope in the missile. This gyro is continuously oriented to the proper azimuth until FIRE, when the A_G brake freezes the gyro azimuth solution. The functional diagram of the A_G brake circuit is found at 107D13.

e. A_G servo system circuits. Refer to the functional diagram of the A_G servo system (TM 9-5000-26, p 49). Voltage +X_I from the intercept point solver

Figure 17. A_G servo in basic servo configuration.

is applied across sine cosine potentiometer A_G 13 the brush arms of which are positioned by the gearing connected to the A_G servomotor generator. The output, $X_I \cos A_G$, goes to the A_G amplifier input network and $X_I \sin A_G$ goes to the time of flight predictor. Voltages $+Y_I$ and Y_I are applied to potentiometer A_G -12 whose outputs, $+Y_I \sin A_G$ and $Y_I \cos A_G$, go to the A_G amplifier input network and the time of-flight predictor, respectively.

f. Controller operation. The A_G DC amplifier is a summing amplifier for $X_I \cos A_G$ and $+Y_I \sin A_G$. The output of the A_G amplifier is a d-c voltage (actuating error) which is used as the input signal to the modulator. The phase and amplitude of the a-c modulator output are respectively controlled by the polarity and magnitude of the d-c input. Note that the A_G modulator is on the same chassis as is the ballistic elevation servo modulator (A_G and B modulator chassis). The LPSA output is applied through contacts of fire relay K3 to the

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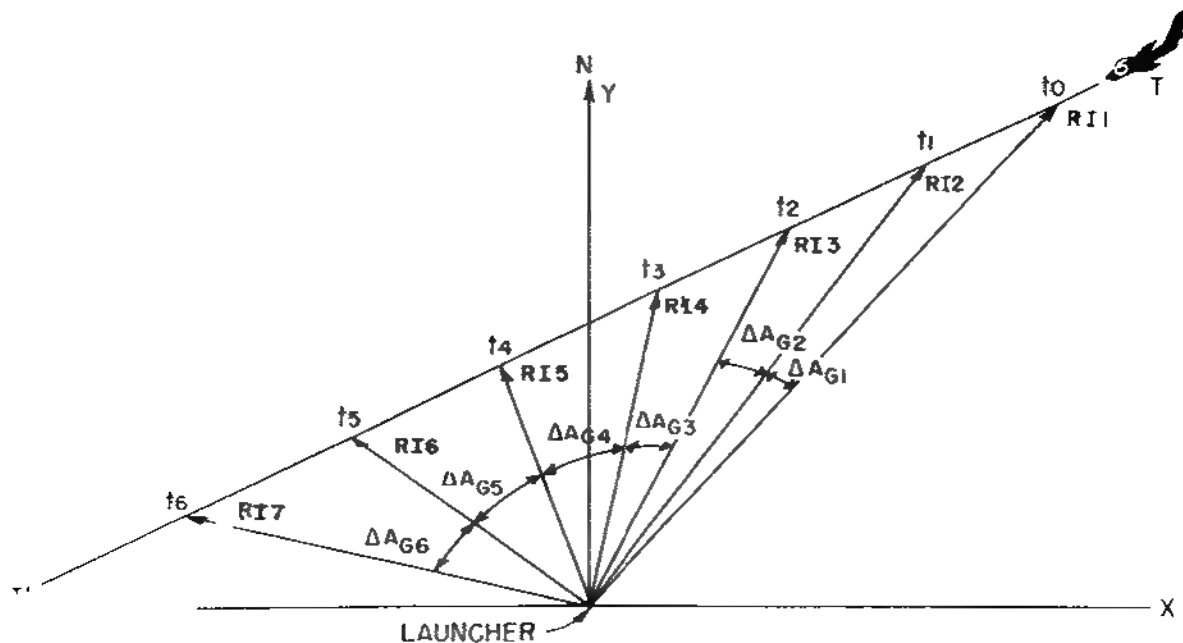


Figure 18. Increase of A_G change as R_I decreases.

control windings of the 2-phase induction motor. When the FIRE button is pressed, fire relay K3 is energized, removing the control field excitation. This is coincident with the braking of the A_G servo gearing.

49. GEOMETRIC GAIN CONTROL (TM 9-5000-26, p 49)

a. Illustration of approaching target. Examine figure 18. This diagram shows the ground projection (TT') of predicted intercept points of a target approaching a defended area. For simplicity the target is assumed to be flying a straight course at constant speed. Equal time intervals (t_0, t_1, t_2) are indicated along path TT'. Note that as the ground range to intercept decreases ($R_{I3} < R_{I2} < R_{I1}$), the change in the A_G angle increases in each succeeding time interval ($\Delta A_{G3} > \Delta A_{G2} > \Delta A_{G1}, \dots$).

b. Change of A_G angle vs ground range. Since the rate of change of the A_G angle increases as the ground range to the intercept point (R_I) decreases, the A_G servo must change the output shaft position faster as R_I decreases. This requirement is met by introducing a circuit which increases the gain of the A_G DC amplifier as R_I decreases. From the block diagram of the prelaunch section of the computer it will be recalled that two voltages representing R_I are used by the time-of-flight predictor. One voltage representing R_I comes from the A_G servo ($-X_I \sin A_G - Y_I \cos A_G$) and the other which represents $+R_I$ comes from

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the ballistic circuits ($R_B + D_B \cos B$). The geometric gain for the A_G servo obviously must use the $+R_I$ solution from the ballistic circuits, since the $-R_I$ voltage is itself an output of the A_G servo.

c. Components. The components used to provide the geometric gain control of the A_G DC amplifier are found at 49B4 and 49B5. The two potentiometers vary the feedback so that the gain of the A_G DC amplifier varies inversely with R_I . The t-potentiometer (T_C-7B) brush arm is positioned by the time-of-flight predictor. This potentiometer provides the R_B component which is a time function. The quantity, $D_B \cos B$, is provided by the ballistic elevation potentiometer, B-4.25, the brush arm of which is positioned by the ballistic elevation servo.

d. Limits. To prevent excessive gain in the A_G amplifier when time of flight approaches zero and B approaches $+90^\circ$, limits are provided in the feedback circuit. The voltage divider in the time card is designed so that 17.7 seconds is the minimum time. This time is present at the junction of the 4,550 ohm resistor and the time card. Taps and secondary resistances on the B card limit the value of $\cos B$ to $+0.20$ ($B = 1,395$ mils). Maximum gain of the A_G amplifier, when t equals 17.7 seconds and B equals 1,395 mils, is 119.5. Minimum gain, when t equals 100 seconds and B equals zero degrees, is 4.14.

50. OPERATION OF THE A_G SERVO DURING STANDBY (TR 9-5000-26, p 60)

a. The GYRO AZIMUTH switch. When the COMPUTER CONDITION switch is in the STANDBY position, the gyro azimuth servo is positioned at the setting of the GYRO AZIMUTH 100'S MILS switch of the computer control panel. This switch is calibrated at 800-mil intervals, beginning at 400 mils, as is shown at 601D3.

b. Setting when attack is imminent. During STANDBY this switch is placed at the setting closest to the azimuth of the expected direction of attack. For example, suppose that a Nike battery were so situated that the expected direction of attack is from the southeast (2,400 mils). The GYRO AZIMUTH switch would be placed either at 2,000 mils or at 2,800 mils. This would place +231.425 volts (23.143 yards) at terminal 522 of the servo cabinet and -9.5725 volts (-9.573 yards) at terminal 523.

c. Voltages X_{GAT} and Y_{GAT} . These voltages are designated X_{GAT} and Y_{GAT} , respectively. (The subscript, GAT, is the abbreviation for gyro azimuth test, since the source of these voltages is the gyro azimuth test voltage divider.) The X_{GAT} and Y_{GAT} voltages are applied to terminals 3 of the X_I and Y_I input networks through contacts of the deenergized relay, K23. During STANDBY the X_{GAT} and Y_{GAT} voltages are the only inputs to the intercept point solver.

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For the assumed setting of S2 at 2,000 mils, the outputs of the $-X_I$ and $-Y_I$ amplifiers are -231.425 and +9.5725 volts, respectively. This would cause the A_G servo to be positioned at 2,000 mils. For all settings of GYRO AZIMUTH switch S2, the ground range to the intercept point is 25,000 yards, and the time of-flight predictor is positioned at 44.67 seconds.

d. Other uses of the GYRO AZIMUTH switch, S2. The gyro azimuth determined by the setting of switch S2 is also used in positioning the roll amount gyroscope in the ACTION condition until the TARGET TRACKED signal is given. At TARGET TRACKED the target position data ($+X_T$ and $+Y_T$) from the target coordinate converter will replace X_{GAT} and Y_{GAT} voltages in the solution for A_G and t . This occurs when NOT STANDBY relay K23 is energized. It should be noted that the X_{GAT} and Y_{GAT} voltages position the gyro azimuth servo during steering static tests, since STEERING TEST relay K28 is energized applying these voltages to the intercept point solver.

51. A_G SLEW DETECTOR (TM 9-5000-26, p 123)

A slew detector is used to monitor the output voltage of the A_G servo summing amplifier. This detector is located on the computer conditioning relay panel and is shown in detail in the upper left corner at 123A1 of 2y. If the A_G servo is positioned correctly, the A_G amplifier output voltage appearing at J2 9 of the slew detector is zero. Under this condition both sections V1A and V1B have equal grid to ground voltages as provided by their respective grid circuit voltage dividers. Sections V1A and V1B are balanced to have equal plate voltages with zero volts at J2 9. With equal plate voltages for both sections of V1, no current flows through A_G SL (gyro azimuth slew) relay K13, and it remains deenergized. If the A_G servo is not positioned to the correct gyro azimuth angle, there is an error voltage at the output of the A_G amplifier and the A_G motor starts turning toward the correct A_G angle. (It should be remembered that there is no A_G slew motor.) If the magnitude of the output of the A_G amplifier exceeds 15 volts, the plate voltages of the two sections of V1 will be sufficiently different to cause K13 to energize. A_G slew relay K13, when energized, prevents the COMPUTER SETTLED relay, K9, from becoming energized.

Section X. TIME OF FLIGHT PREDICTOR

52. GENERAL

a. Purpose. The purpose of the time-of-flight predictor is to determine a correct time of flight of the missile from the end of FIRE +7 seconds to the predicted intercept point. The time is indicated in a window on the front of the servo cabinet. At this stage of operation, there is a constant dead time (7 seconds)

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reckoned to provide compensation for mechanical functions which must always occur between the instants of fire and roll stabilization. Together, these figures yield the total time which will elapse between FIRE and intercept. A block diagram of the time-of-flight predictor is shown in TM 9-5000-26, page 56.

b. Inputs. The inputs to the servo are $-R_I$ from the A_G servo and $R_B + D_B \cos B$ from the ballistic circuits.

c. Assumptions. In previous discussion of the determination of the intercept point, the time of flight of the missile was assumed. The time was needed, along with target velocity, to calculate the distance the target would move between the instants of FIRE and intercept. In this discussion correct values of intercept point, gyro azimuth, and ballistic data will be assumed. Interaction will be treated later.

d. Outputs. The controlled outputs are a mechanical positioning of potentiometer brush arms and voltage analogs of the time of flight.

e. Components and their locations. Some of the physical components which constitute the time-of-flight servo are also used in the time to intercept servo during the steering phase of computer action. Two identical input networks, t_{p1} and t_{p2} , are located below the t amplifier in the left amplifier frame. During the prelaunch phase, network t_{p1} feeds the error voltage to the t -amplifier. The t_{p2} network is used in conjunction with the time slew control circuits discussed in section XII. The normal computer servo modulator and low power servo-amplifier which follow the t amplifier are located in the rear bay of the left amplifier cabinet. The modulator chassis is shared with the t_{SLR} circuit. The time to-intercept servo assembly at the center of the computer servo cabinet contains the remainder of the components: servomotor generator and associated gearing and switches, a slew motor, and potentiometer cards. Two DC amplifiers, $+t$ and $-t$, are also located in the left amplifier frame.

53. MATHEMATICAL ANALYSIS

The equation used by the time-of-flight predictor to solve for a time of flight is

$$-R_I + R_B + D_B \cos B = 0. \quad (27)$$

$R_B + D_B \cos B$ is an implicit function of time as discussed in section VII above. In figure 19, the ballistic ground range is seen to be composed of two parts. The first is the distance from the launcher to the ground projection of the center of the constant time circle being used. The second is the ground projection of the constant time circle radius. If the ballistic elevation is B , then simple

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trigonometry gives the ground projection of the radius as $D_B \cos B$, which is always a positive quantity. $-R_I$ is also a function of time, since

$$R_I = X_I \sin A_G + Y_I \cos A_G \quad (28)$$

and

$$X_I = X_T - X_L + \dot{X}_P(t + t_d) \quad (14)$$

$$Y_I = Y_T - Y_L + \dot{Y}_P(t + t_d). \quad (15)$$

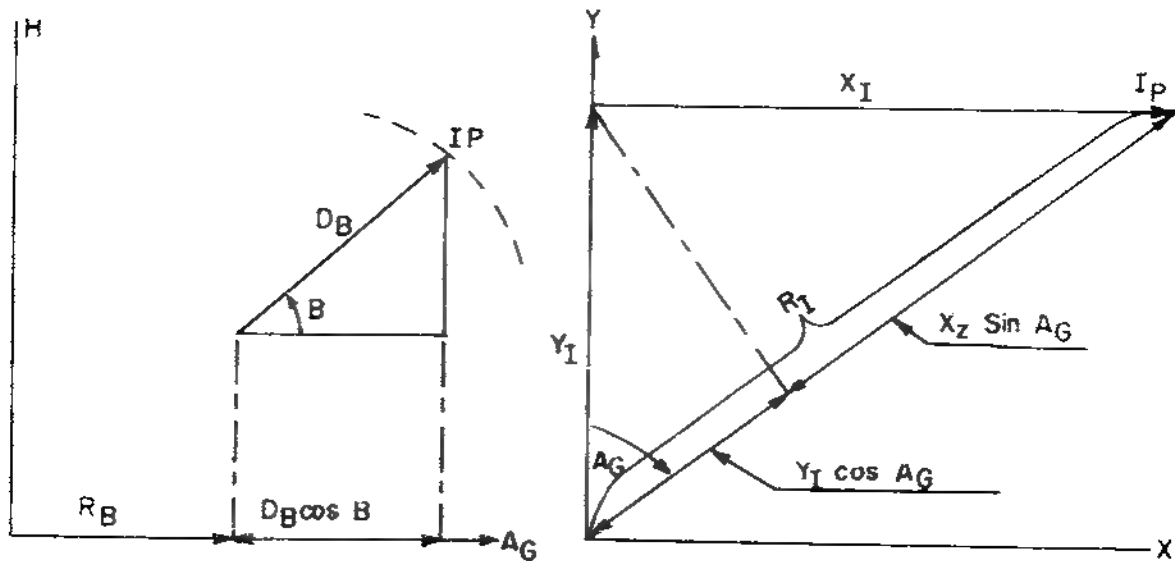


Figure 19. The horizontal range triangles.

Substituting these in equation (28)

$$\begin{aligned} R_I = X_T \sin A_G - X_L \sin A_G + \dot{X}_P(t + t_d) \sin A_G + Y_T \cos A_G - Y_L \cos A_G + \\ \dot{Y}_P(t + t_d) \cos A_G - (X_T \sin A_G + Y_T \cos A_G) - (\lambda_L \sin A_G + Y_L \cos A_G) + \\ (\dot{X}_P \sin A_G + \dot{Y}_P \cos A_G)(t + t_d). \end{aligned}$$

$$R_I = R_T - R_L + (t + t_d) \dot{R}_P. \quad (29)$$

This quantity is also positive by definition. Both represent the horizontal range from the launcher to the intercept point. R_I is the computed range, and $R_B + D_B \cos B$ is the ballistic range. If the missile is to destroy the target, the ballistic and computed ranges must be equal. The problem is to find a value of

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time that will make equation (27) true. The t servo solves the problem by the method of successive approximations. The time-of-flight predictor selects a value of t , substitutes this t in equation (27), and tests the solution. If the solution is not zero, another value of t is used in the same process. Eventually the correct time of flight is determined.

54. SIMPLIFIED FUNCTIONAL OPERATION

The time of flight determined by the time of-flight predictor (fig 20) is the time required by the missile to reach the intercept point from its position at the end of roll stabilization. Dead time takes care of the period between FIRE and the end of roll stabilization. During the prelaunch calculations t is constantly changing and t_d is a constant 7 seconds. The circuits used to find the time of flight readily fit into the picture of a basic closed loop control system. The controlled variable t is used to modify the two reference inputs. A comparator (t -amplifier and input network) compares the two references. The difference between the references is the actuating error, e . The error passes on to the drive elements of the servo. In the modulator the d-c error voltage becomes an a-c error voltage. The low-power servoamplifier raises the power to a level sufficient to drive the servomotor generator. This motor positions a number of time potentiometer brush arms. Alteration of the brush arm positions affects both reference inputs. This is accomplished in the feedback elements (intercept point solver and ballistic circuits). The outputs are a mechanical position of the brush arms and a d-c analog voltage.

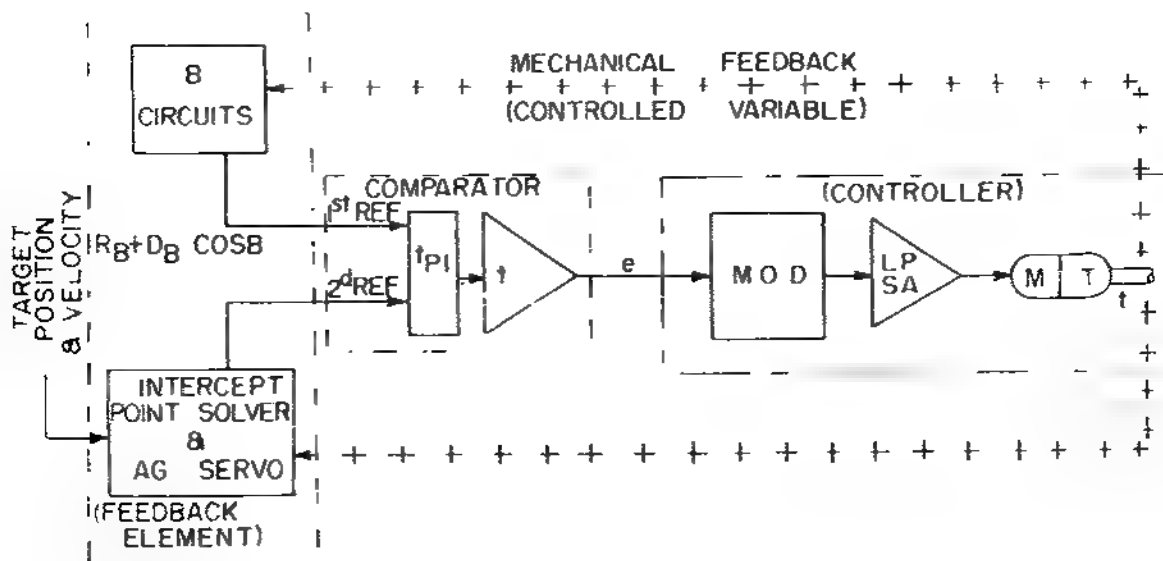


Figure 20. The time-of-flight predictor as a basic closed-loop control system.

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55. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, pp 49 and 83)

a. Reference inputs. All inputs to the t_{p1} network at 49C8 have a scale factor of 1 mv/yd. R_B , part of the first reference voltage, is received on terminals 5 and 6. It is usually a positive voltage. $D_B \cos B$, the rest of the first reference voltage, is brought in on terminal 7. This is always a positive voltage. The sum, $R_B + D_B \cos B$, is also always positive. The two voltages which represent $-R_I$ are received on terminals 3 and 4 as $-X_I \sin A_G$ and $-Y_I \cos A_G$, respectively. Each of these is always a negative voltage. They are derived from A_G potentiometer cards A_G-13 and A_G-12 . Refer to page 49B3.

b. Error voltages. The t-amplifier and input network can compare $R_I(R_B + D_B \cos B)$ and $R_I(X_I \sin A_G - Y_I \cos A_G)$ since they are of opposite polarity. If the result of the comparison is zero, the value of t is correct. If the result is not zero, the time of flight predictor positions itself to a new value of t and makes the comparison again. This process is repeated until there is zero error. If the sum of equation (27) is a positive voltage, the value of t selected is too great. Thus, a negative voltage at the output of the t-amplifier will decrease time, and a positive voltage will increase time.

c. Steering relay. At 83A4 the lead from the t_{p1} network to the t amplifier passes through contacts of steering relay K79. When the steering relays are energized, t_{p1} network is replaced by the t_s network. This switching provides a smooth transition of time between the prelaunch and steering phases of operation. If the target velocity does not change appreciably during dead time rundown, the value of t determined in the prelaunch phase will be accurate for steering.

d. Gain. The gain of the t-amplifier is 51. Since 36 volts at the input to the modulator will drive the servomotor at the maximum rate of 4 seconds per second, an error of 706 yards will cause the t-servo to operate at maximum speed.

e. Modulator. The t-modulator differs from other computer modulators in that only 60 volt, 400 cps cathode excitation is used. This reduces any oscillation of the servo.

f. Standby solution. During standby, X_{GAT} and Y_{GAT} voltages are applied through nonstandby relay K23 to the intercept point solver. This causes the t-servo to position itself at about 45 seconds, the time of-flight solution to an intercept point of 25,000 yards ground range and zero elevation. These voltages are generated by the gyro azimuth test voltage divider.

56. THE $+t$ AND $-t$ AMPLIFIERS

A number of computer circuits utilize a d-c voltage which represents time. At 83B1 the $+S$ voltage is brought into time card T_C-14B . The top of the card represents 100 seconds time of flight; the bottom, zero seconds. Until the fine-time relay, K38, is energized, a voltage proportional to time is furnished by T_C-14B to the $-t$ -input network on terminal 3. At 24 seconds time to intercept, the t voltage comes from the fine-time card. The $-t$ -voltage output has a scale factor of 1 volt per second. This voltage is used in the initial turn section of the computer and in the vertical plotting board circuit. The $+t$ amplifier merely reverses the polarity of the $-t$ -voltage for the prelaunch and initial turn sections, the second-per-second bias network, and the steering error solver. A more detailed discussion of this circuit is found in TM 9-5000-15, paragraph 67.

57. MECHANICAL OPERATION (TM 9-5000-26, pp 57 and 58)

a. General. Refer to TM 9-5000-26, page 58, in which the time-to-intercept servo assembly is illustrated. The coarse-time cards are located in the larger casing, R1. The travel of the shaft driving R1 is restricted to 165° of rotation. The extreme positions in this range represent zero and 100 seconds. At -1.5 seconds, and at +103 seconds, mechanical stops are provided to prevent the brush arms running off the limits of the cards. The gear at the extreme left has cams attached to it which actuate the time switches, S1 through S6. The gear at top right has cams which actuate the time switches, S7 and S8. Coarse and fine time dials are used to provide a quick means of determining the position of the brush arms. A manual drive permits the repairman to position the brush arms when servo d-c is off.

b. Servomotor and slew motor. Ordinarily the t -servo assembly is driven by servomotor generator MG 1. When the time slew motor is used, the centrifugal clutch engages the slew motor to the shaft and the servomotor drive gear is released. The servomotor and slew motor never drive the gear mechanism simultaneously. The motors are each geared down to a speed ratio of 3,900:7 by separate gear trains. The remainder of this gearing reduces the speed ratio to 6,334:1 for the coarse potentiometer and 3,176:4 for the fine potentiometer.

c. Slip clutch. A slip clutch is provided in the gear train common to both the servomotor and the slew motor drive. This clutch prevents stalling of either motor when the mechanism is halted by a mechanical stop. This protects the motor windings, which would draw excessive current if the rotor were stopped while excitation voltages are applied. The slip clutch slips at a torque equal to about one-half that developed by the motor on the clutch shaft if the shaft is held stationary.

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d. Limit switches. Cam-operated limit switches S5 and S6 are provided to protect the slip clutch against overheating when a limit is reached. Refer to TM 9-5000-26, page 57. If full excitation is applied to the servomotor when the mechanism is halted by a stop, the clutch would be driven at a speed at which friction heat becomes excessive. The lower limit switch, S5, is opened at 10.5 seconds, and the upper limit switch, S6, is opened at 101 seconds. When either limit switch opens, the short circuit across 40,000-ohm resistor R3 is removed, causing motor excitation to pass through R3 before it reaches the field winding of the servomotor. The drop across R3 reduces the excitation voltage enough to prevent damage to the slip clutch. The cam-operated switches, S1 and S2, prevent the slew motor from driving the mechanism against either mechanical stop. The lower limit switch, S1, is opened at 5 seconds, the upper limit switch, S2, at 95 seconds.

e. Coarse-time cards. The t-shaft positions brushes on the 16 coarse time cards located in R1. Of these, 8 are used in the prelaunch section, 1 in the initial turn section, 1 in both prelaunch and steering sections, and 6 in the steering section only. There is space for four spares for eventual computer modifications.

f. Fine time cards. R2 contains the five fine-time cards. The shaft of R2 turns at one eighth the speed of the coarse-time shaft. These cards are all used in the steering section. The brushes on these cards are positioned through 330° only, representing the last 25 seconds of time to intercept. An insulated bridge is provided for the brushes for the remaining 30° of rotation.

g. Specific time cards and their uses. Coarse-time cards T_C-15A , T_C-15B , and T_C-14A are used in the intercept point solver to determine the distance the target will travel between FIRE and intercept. Cards T_C-8A and T_C-7B act as geometric gain controls for the B and A_G servos, respectively. Cards T_C-8B , T_C-6A , and T_C-6B operate in the ballistic servo to determine H_B , D_B , and D_B . Card T_C-14B is used in the d-c amplifier circuit to furnish a d-c voltage analog of time. The other cards are described in their respective circuits.

58. ILLUSTRATIVE PROBLEM

Continue the intercept point problem presented in paragraph 36.

a. Known data. The tabulated data given in that problem was:

$$\begin{array}{lll} X_T = 50,000 \text{ yd} & \dot{X}_P = +200 \text{ yd/sec} & X_L = -2,000 \text{ yd} \\ Y_T = -50,000 \text{ yd} & \dot{Y}_P = +200 \text{ yd/sec} & Y_L = 1,000 \text{ yd} \\ H_T = 14,000 \text{ yd} & \dot{H}_P = 5 \text{ yd/sec} & H_L = -100 \text{ yd} \end{array}$$

b. First solution. Assume that the time of flight was 83 seconds. With a dead time of 7 seconds, the target would have traveled 90 seconds before intercept. Is the 83 second time of flight correct? Using equation (28) above, the intercept point is found to be:

$$X_I = 50,000 + 2,000 + 200 \times 90 = 30,000 \text{ yd}$$

$$Y_I = -33,000 \text{ yd}$$

$$R_I = \sqrt{X_I^2 + Y_I^2} = 44,600 \text{ yd}$$

$$H_I = 13,650 \text{ yd, or } 40,950 \text{ ft.}$$

Plot the point (H_I , R_I) on the ballistic chart of figure 10. The point lies approximately on the 75 second time circle. Then the 83-second time of flight is too long.

c. Second solution. Split the 8 second difference and try 79 seconds. Do not forget to add dead time. Then

$$X_I = 30,800 \text{ yd, } Y_I = -33,800 \text{ yd, } R_I = 45,710 \text{ yd, } H_I = 45,750 \text{ ft.}$$

This point lies on the 77 second time circle. Time is too great.

d. Third and correct solution. Split the 1-second time difference. With a 78-second time of flight:

$$X_I = 31,000 \text{ yd, } Y_I = -34,000 \text{ yd, } R_I = 46,100 \text{ yd, } H_I = 41,025 \text{ ft.}$$

This point plotted hits right on the 78-second time circle, and 78 seconds is the correct time of flight.

e. Solving time of flight with computer. The process of determining the time of flight above is comparable to the prelaunch computer process. First, the intercept point solver finds the coordinates of the intercept point (equation 30). The AG servo then determines R_I from X_I and Y_I (equation 31). H_I is then used by the ballistic circuit to determine the ballistic data (plotting H_I and R_I on the ballistic chart of figure 10). The time-of-flight predictor compares the ballistic data with the computed ground range (75-second ballistic time against the assumed 83-second target flight). The answer is wrong, and a shorter time, 79 seconds, is tested. Finally the correct time, 78 seconds, is found.

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Section XI. SLEW CONTROL CIRCUIT

59. GENERAL

The slew control circuit is a servomechanism used in conjunction with the t servo to set the t -servo rapidly to the approximate operational value of time. Most of its components are located on the slew control and timer panel at the rear of the right amplifier cabinet. Also on this chassis is the TDE + 4 delay timer. The unit is similar to the A_G slew detector, but with circuits added to control the direction of rotation of the slew motor. The dual triodes (59A3) make up a balanced bridge and act as switch tubes to control the operation of several relays. These relays control the rotation of the slew motor located in the time-to intercept servo assembly. The inputs and input network to the slew control circuit are identical to those of the prelaunch t -servo (time-of flight predictor). This network is located below the t -amplifier on the left amplifier cabinet frame. The output is a rotation of the t -servo shaft at a rate of 15 seconds per second.

60. SIMPLIFIED FUNCTIONAL OPERATION (fig 21)

The input terminals of the t_{p2} network are in parallel with those of the pre launch t -servo (t_{p1}). These networks are located one over the other on the left amplifier frame. This t_{p2} network serves as the error measuring device of the servo. It permits comparison of a variable signal from the intercept point solver with a reference from the ballistic elevation servo. Each of these

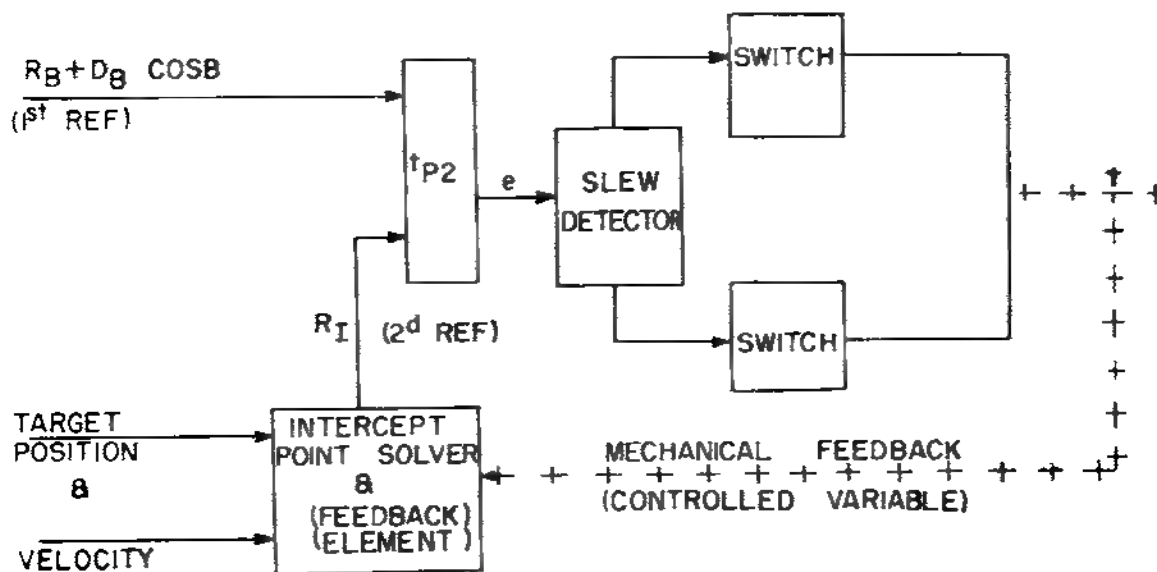


Figure 21. Time slew control, simplified functional schematic.

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represents the ground range to the intercept point. The value of R_I from the intercept point solver, $-X_I \sin A_G - Y_I \cos A_G$, can be altered by mechanical rotation of the t-potentiometer brush arms ($X_I - X_T - X_L + \dot{X}_P(t + t_d)$). When the sum of the input signals becomes either +10 or -10 volts, the actuating error, e , will unbalance the bridge of the slew detector. Depending on the polarity of the error, the slew detector will operate one of two electronic switches. Either switch causes the t-slew motor to drive the mechanism of the t-servo in the direction that will reduce the actuating error. This mechanical rotation of the brush arms is the controlled output of the time slew control circuit. It acts to make R_I equal to the reference, $R_B + D_B \cos B$, but of the opposite polarity.

61. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, p 59)

a. Condition of circuit with no error voltage. When the proper solution of time of flight has been reached in the time slew control circuit, the actuating error is zero. Both grids of V3 are at ground potential, and V3A and V3B are conducting equally. The slew detector bridge is balanced. The voltage dividers coupling the plates of the bridge tubes to the grids of the switch tubes, V2A and V2B, are identical; the grids are at equal potentials. The operating points of V2A and V2B were chosen so that, with no time error, these tubes would be cut off. No current is drawn through either the increase time relay, K4, or the decrease time relay, K5. Each remains deenergized. Neither time-slew-increase relay K6 nor time-slew-decrease relay K2 can be energized because of the open contacts of K4 and K5. The slew relays are the ones which activate the time slew motor.

b. Condition of circuit with a 10-volt error. Now consider a +10-volt error at the input to the t_{p2} network. This corresponds to a +10-second error. The t servo would require 2.5 seconds to correct the error; the t-slew control circuit only 0.67 second. The +10-volt error at the t_{p2} input terminals is reduced, by an R-C voltage divider, to +2 volts at the grid of V3A. When the capacitor, C2, charges to +2 volts, V3A increases conduction, causing cathode voltage to rise and plate voltage to drop. The drop in plate potential causes switch tube V2A to quit conducting. The rise in cathode potential is coupled to the cathode of V3B, decreasing the plate current. The plate potential rise of V3B is direct coupled to the grid of V2B. V2B conducts rather heavily, drawing current through decrease-time relay K5. As K5 energizes, its contacts supply a ground to the time-slew-decrease relay, K2, through closed contacts of the missile-away-locking relay, K7, and limit switch, S1. The time slew decrease relay contacts apply to the slew motor the voltages which will rotate the slew motor in the direction that will reduce the predicted time of flight. Similarly, a negative 2-volt error on the grid of V3A will cause the slew motor to rotate in a direction to increase the predicted time of flight. If the relay, K2, is energized, all

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contacts above it are moved. Ground is supplied to J2-8 and 120-volt, 400-cps power to J2 6. The induction motor turns, and slews the t-servo at a rate of 15 seconds per second.

c. Return to quiescent state. When the actuating error is reduced sufficiently to discharge C2 to +1 volt (to -1 volt if the time error is negative), the switch tubes are both returned to the quiescent state. K5, and then K2, deenergize. As the K2 contacts return to normal, -28 volts is supplied to the slew motor through J2-2. This voltage saturates the winding and stops the motor quickly. Note that contacts of the MAL relay are in series with the ground leads to the slew relays. After the missile has become airborne, it is undesirable for a time slew to occur, accidentally or otherwise. A close approximation of the proper time to intercept has already been obtained.

62. MECHANICAL OPERATION (TM 9-5000-26, p 57)

When the slew motor (B1) has reached one-half speed in either direction from a standstill, centrifugal switch S9 in the t-servo assembly is closed. This permits -28 volts to reach the open contacts of either the time slew-increase or the time slew decrease relays. After the error has been reduced and the time slew relay deenergizes, these contacts close to permit the -28 volts to brake the slew motor. Switch S9 opens as the motor slows down. Limit switches S1 and S2 are operated by cams located on the main gear of the t-servo: S1 whenever time is less than 5 seconds, S2 whenever time is greater than 95 seconds. S1 and S2 prevent slewing and injury of the time servo when the t-servo gears are near their mechanical stops. For example, if the time servo is positioned at 96 seconds, damage might occur to the gearing if a time-slew-increase were made. However, S2 opens, preventing the time-slew-increase from taking place. The time servo may be slowed down because S1 still provides a ground path for relay K2.

Section XII. SERVO INTERACTION

03. GENERAL

For simplicity, the foregoing discussions of the prelaunch servo systems have assumed that no interaction takes place between the various servos. A check of the servo circuits shown in TM 9-5000-26, page 49, shows that this is not true. Any action in one servo immediately affects another servo. For example, the inputs to the intercept point solver used to calculate X_I are X_T , X_L , and \dot{X}_P . These inputs are not affected by the servo units, but are determined in other parts of the computer. However, \dot{X}_P is multiplied by time before it is added to X_L and X_T and is therefore a function of time. This is also true

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of the inputs which evolve Y_I and H_I . The outputs of the intercept point solver, two of which are the inputs to the gyro azimuth servo, then are functions of time. Any change in time will, therefore, be reflected in the gyro azimuth servo solution, causing a change in A_G . One of the inputs to the time of flight predictor is the negative of equation (28).

$$R_I = X_I \sin A_G + Y_I \cos A_G. \quad (28)$$

This equation indicates that R_I is a function of A_G . Therefore, positioning the time servo depends upon the gyro azimuth solution. When A_G changes, t will change; conversely when t changes, A_G will change. The equations which are solved by servos must be simultaneous equations. The values for A_G , t , and B must satisfy all equations.

64. SUCCESSIVE APPROXIMATIONS

The process by which the equations are solved simultaneously is that of successive approximation. Assume that the time servo is set to some particular value of time. This value appears on the time cards. The t_d potentiometers are set at 7 seconds. X_P and \dot{Y}_P , multiplied by the particular value of time assumed above, are applied as inputs to the intercept point solver. The actual time chosen is of no concern. Using the products of \dot{X}_P and \dot{Y}_P by time and summing these with the appropriate launcher parallax and target position data, the values for X_I and Y_I are determined. It is then possible to determine R_I from equation (28), above. This value of R_I is used in equation (27),

$$R_B + D_B \cos B - R_I = 0, \quad (27)$$

to position the time servo. If the testing of equation (27) does not yield zero, the time servo moves until the equation is satisfied. A more correct solution for time is found. This change in the time solution changes the value of A_G , since it will change the value of the inputs to the intercept point solver. Now that the new value of time is more correct, the new predicted intercept point is more correct. The new settling point of the gyro azimuth servo is more correct, as is the new determination of the ballistic elevation. This process is then repeated. With each repetition A_G and t should more closely approximate the simultaneous values. Since the servos run continuously, only a short time is required to approach the proper values.

65. INTERACTION OF THE TIME AND BALLISTIC ELEVATION SERVOS

The interaction between the time and ballistic servos will be discussed while ignoring the gyro azimuth servo. If the ballistic elevation changes, $D_B \cos B$ will change. Since $D_B \cos B$ is a term in equation (27) above, this will cause a

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corresponding change in the time solution. The inputs to the intercept point solver have been shown to be a function of time. As time changes, H_I will change. The ballistic servo uses equation (19),

$$-H_I + H_B + D_B \sin B = 0. \quad (19)$$

If H_I changes, then the ballistic solution must change the value of the remaining variables of equation (19) so their sum will equal zero. In causing a change of values for the variables of equation (19), the ballistic servo will change the value of $D_B \cos B$ in equation (27), above. When $D_B \cos B$ changes, the value of time selected is no longer correct. The time servo will reposition itself to correct equation (27) and the process will be repeated. It would be difficult to illustrate the actual interaction among the three servos without a lengthy mathematical discussion. However, the relationship between variable quantities is readily seen. The only manner in which a true solution for all three servos can be reached is to position each correctly.

CHAPTER 3

THE INITIAL TURN SECTION

Section I. THE INITIAL TURN PROBLEM

66. THE INITIAL TURN PROBLEM

a. General. Two situations exist which threaten to reduce the ability of the Nike I battery to attack targets under all conditions. These situations arise from the limitation imposed on the battery by the need for a booster disposal area and by the maximum tracking rates of the missile-tracking radar. The launcher erecting arm is slanted 5° from the vertical toward the booster disposal area. Since the launcher is fixed in position it cannot be pointed in any other direction. The missile-tracking radar is limited to a maximum rate of 750 mils per second in both azimuth and elevation.

b. Problem imposed by booster disposal. One of these situations could arise when the missile is directed toward an intercept point far removed from the booster disposal area. By the time the missile has completed the 7g dive it is flying almost horizontally, with a high ground speed, and may be a considerable distance from the gyro reference plane. If no turn order were applied prior to the completion of the 7g dive, the steering orders required to bring the missile back into the gyro reference plane at the termination of the dive might result in turns which would exceed the 70° gimbal limit. This would prevent the missile from intercepting close-in targets. The initial turn section eliminates the possibility of this situation by producing outputs which bring the missile, after roll stabilization, into a plane parallel with, and close to the gyro reference plane. Although the missile may be a short distance from the gyro reference plane at roll stabilization, the initial turn section prevents this distance from increasing as the missile dives. Thus, after the missile dives and the ON TRAJECTORY signal is received, the steering orders required to turn the missile onto the intercept course will not cause it to exceed the 70° gimbal limit.

c. Problem imposed by maximum tracking rates. The other situation could arise if the missile flight path were to pass close enough to the missile-tracking radar to exceed the maximum tracking rates of the radar antenna, thus causing the radar to lose the missile. The initial turn section eliminates this possible situation by determining whether or not there is danger of the missile passing too close to the MTR. If the danger exists, the initial turn section produces outputs which cause the missile to skirt the missile-tracking radar. When the missile has safely passed the radar, the initial turn section removes the skirting

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turn order and, if necessary, causes the missile to fly parallel to the gyro reference plane until the ON TRAJECTORY signal is received.

67. INITIAL CLIMB AND TURN ANGLES

During emplacement, the launcher is oriented in the direction of the booster disposal area, and the erecting arm is normally tilted 5° from the vertical in the direction of that area. After the missile is launched, the booster separates from the missile and lands in the booster disposal area. A missile launched under these conditions never starts out vertically. Furthermore, since the booster disposal area and the intercept point are rarely at the same azimuth, the missile will seldom be headed in the direction of the intercept point. Consequently, the missile will have initial climb and turn angles different from zero. Even if the thrust on the boattail of the missile were evenly distributed, the missile will always be less vertical at roll stabilization than at launch because of the effect of gravity. Thus, the climb and turn angles will increase during the missile's flight. Other factors which may affect the climb and turn angles are uneven booster thrust and mechanical transients, which change the direction of the missile at booster separation. Figure 22 indicates the limits of the climb and turn angles which may exist at the end of roll stabilization. These limits are $+15^\circ$ for both the climb and turn angles. In the ideal situation it would be desirable to launch the missile vertically; then, when the 7g dive is applied, the missile would execute a pure dive in the gyro reference plane, and the problem discussed would not exist. However, because of the booster disposal problem, the missile is not launched vertically. It must always be launched in the direction of the booster disposal area. When the 7g dive is applied, if no initial turn order accompanied it, the missile would execute a pure dive, but not in the gyro reference plane. Under these circumstances, the trajectory of the missile over the ground would be as shown in figure 23. This figure represents a situation where the booster disposal area is in a direction 3,400 mils greater than A_G . The position of the launcher is shown by the letter L. In the section of the trajectory from L to A (fig 23), the missile may move out a considerable distance from the gyro reference plane. By the time the missile is at a ground distance of about 3 miles, the missile will be flying almost horizontally with a high ground speed. By this time the ON TRAJECTORY signal will have been received by the computer and the steering phase will have commenced. Turn orders are required to turn the missile back to the gyro reference plane. However, if the remaining time to intercept is short (target close in), it may not be possible to guide the missile back toward the intercept point fast enough to intercept the target; or the turn orders required may be of such magnitude that gimbal limit will be reached. To insure that this situation will not exist, the initial turn section issues turn orders which change the dive from a pure 7g dive to a turning dive which results in the missile flying a zero turn angle course. Once the zero turn

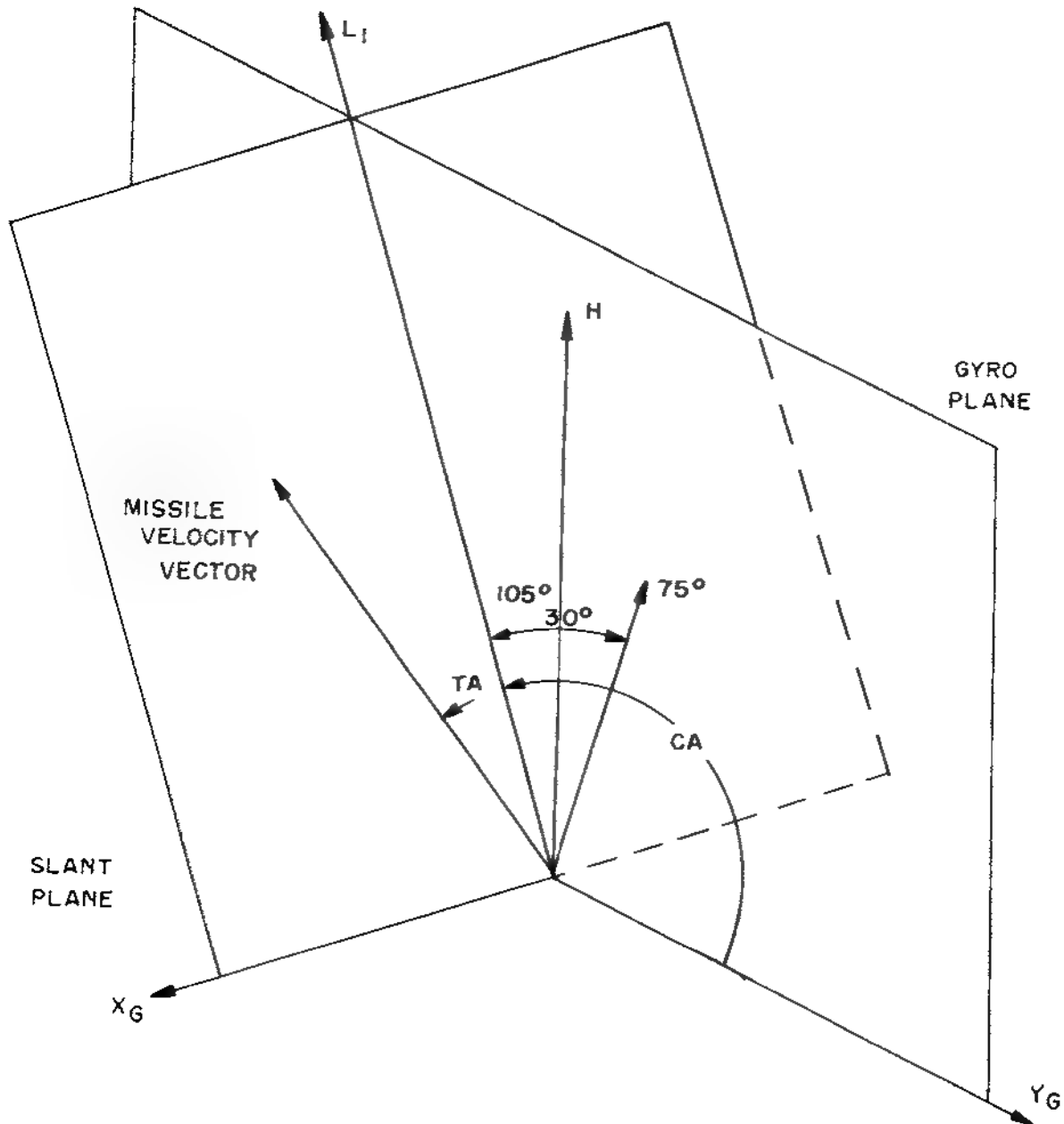
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Figure 22. Limits of climb and turn angles during boost.

angle is established, the initial turn section continues to produce outputs which cause the missile to maneuver to maintain this zero turn angle. The missile will then fly in a plane parallel with, and very close to, the gyro reference plane, and the ground path of the missile will be parallel with the Y_G axis.

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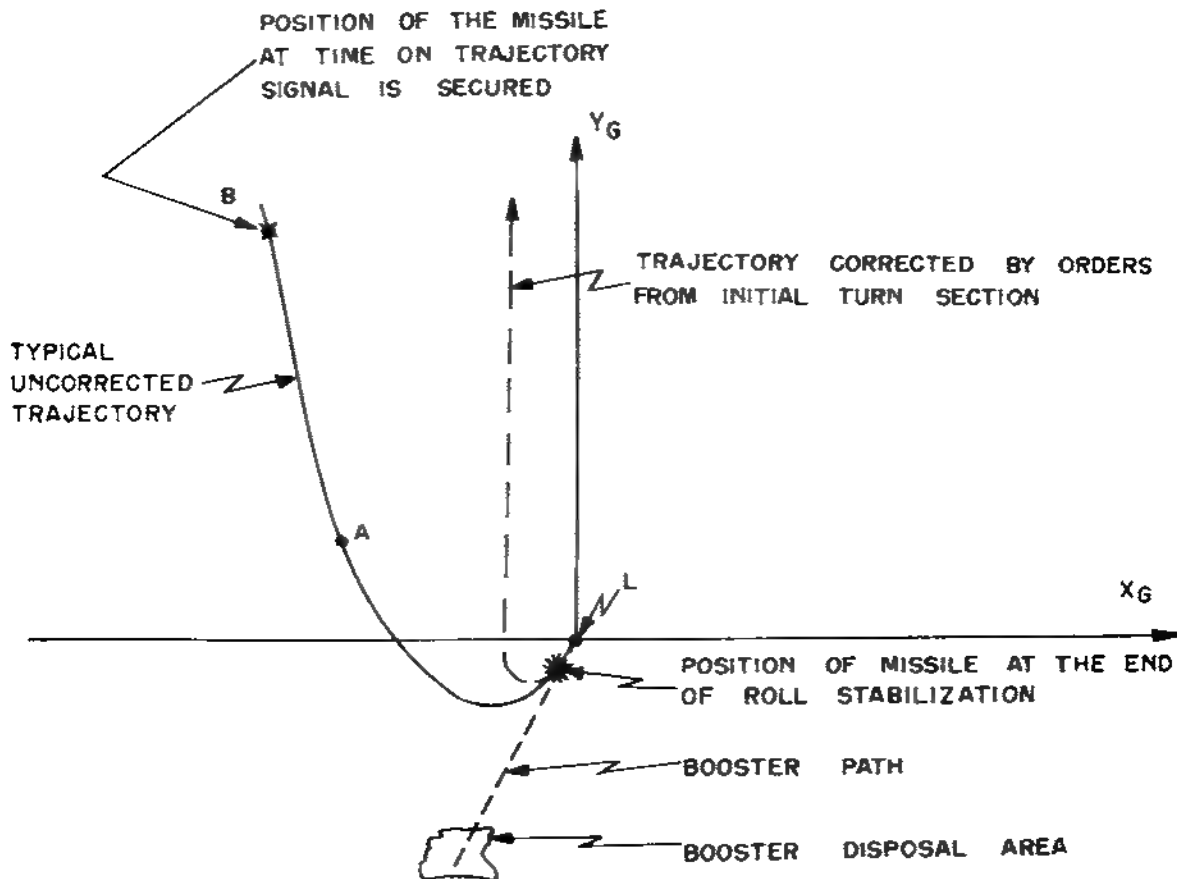


Figure 23. Typical uncorrected missile trajectory.

68. DEVELOPMENT OF THE SKIRTING TURN ORDER

The situation in which the missile may pass too close to the missile tracking radar, exceeding the maximum tracking rates of the radar and thereby losing the missile, is shown graphically in figure 24. The circle around the point marked MTR indicates the ground area which must be skirted by the missile. This area is called the critical zone. If the missile path over the ground passes through this zone, the maximum tracking rates of the radar will be exceeded and the MTR will lose the missile. The size of this critical zone depends upon several factors. One is the maximum tracking rates of the missile-tracking radar (750 mils per second). Another is the ground velocity of the missile as it passes the MTR antenna. The ground velocity of the missile is, in turn, dependent upon the direction the missile is headed in relation to the direction of the intercept point and upon the initial climb and turn angles which exist at roll stabilization.

The second function of the initial turn section is to insure that the missile does not pass over the critical zone.

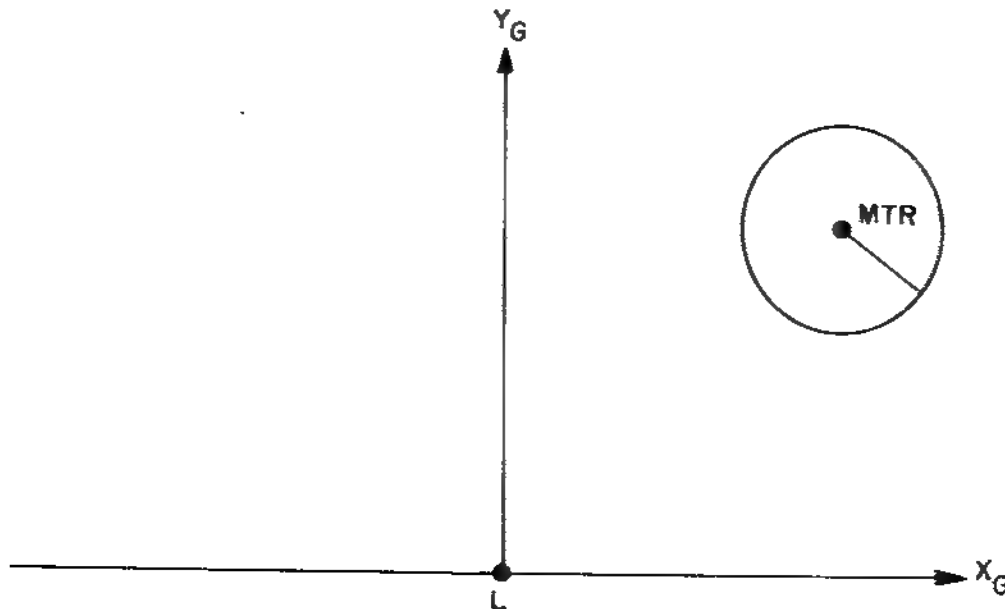


Figure 24. Critical zone around MTR.

69. THE CRITICAL TURN ANGLE AND THE DIFFERENCE TURN ANGLE

a. General. In its solution to the problem just discussed, the initial turn section must determine two things. It must determine the position of the MTR as related to the flight path of the missile, and it must determine the size of the critical zone. This is done by determining two angles. These are the critical turn angle (CTA) and the difference turn angle (DTA).

b. The critical turn angle. The critical turn angle is defined as the imaginary turn angle which, if applied at roll stabilization, would cause the missile to fly directly over the missile-tracking radar. The initial turn section of the computer uses the climb angle (CA), the distance along the X_G axis from the MTR to the missile (X_{GM}), and the ground range from the TTR to the launcher (R_G) to determine the correct value of CTA for any given position of the missile-tracking radar. The ground range from the TTR to the launcher is an approximation of the MTR to launcher distance. The correction for this error is made in the DTA solution. In figure 25, area I represents a position of the MTR to the right of the Y_G axis. The ground path of the missile which results when the missile attains and then maintains the CTA is shown passing through the center of area I. The CTA is positive when the MTR is to the right of the Y_G axis,

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RELATIVE POSITIONS OF MISSILE - TRACKING
RADAR AND MISSILE AT THE END OF ROLL
STABILIZATION WITH VARIOUS VALUES OF
CLIMB AND TURN ANGLES

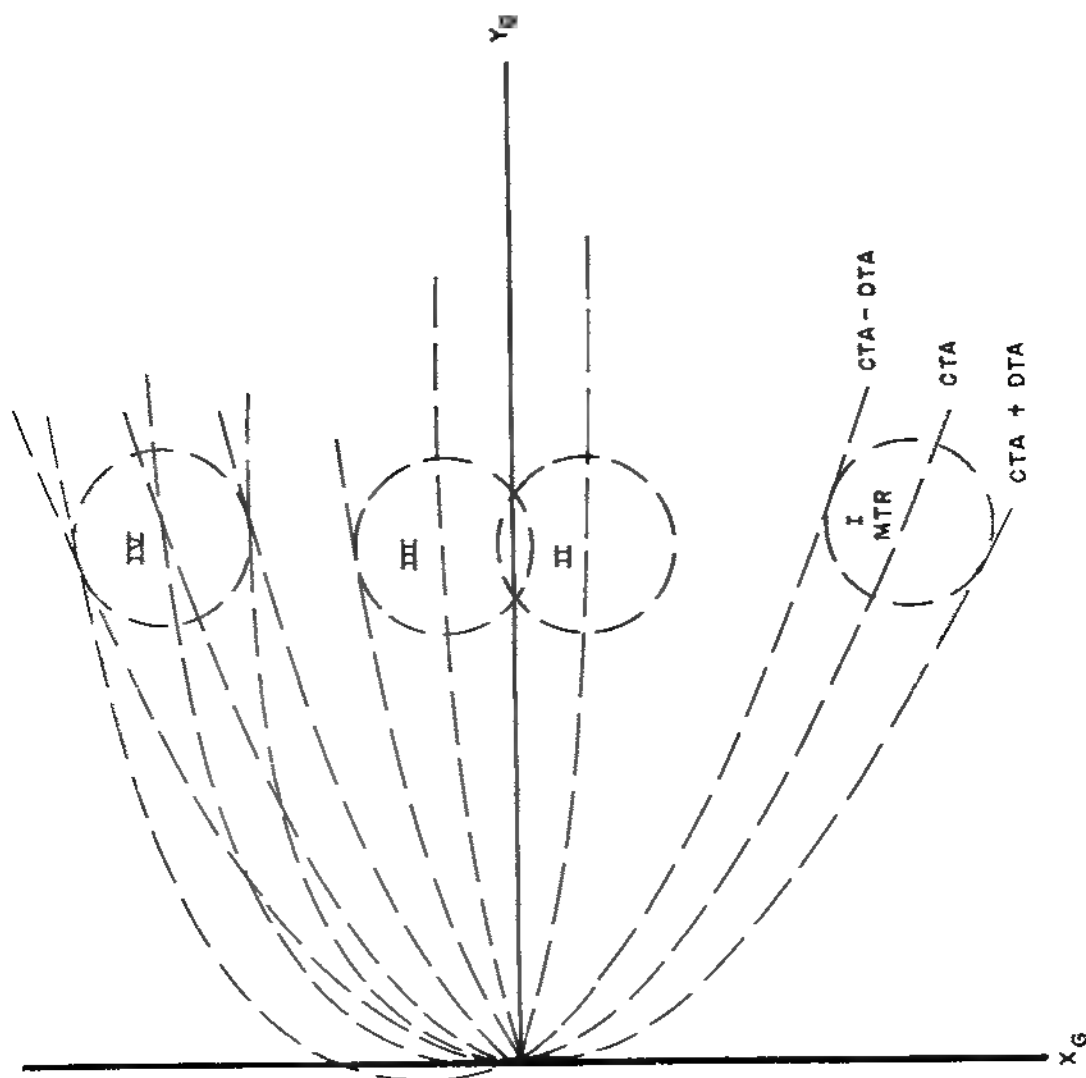


Figure 25. Ground plot of missile trajectories and MTR positions.

looking from the launcher; negative when the MTR is to the left. Note that two ground paths pass through the center of area IV in figure 25. The coarse, broken curve represents the ground path of a missile with a CTA which is dependent upon a climb angle equal to or less than 90° . The fine, broken curve represents the ground path of a missile with a CTA which is dependent upon a climb angle greater than 90° .

c. The difference turn angle. The difference turn angle defines the size of the critical zone. It is defined as the angular difference between the critical turn angle and that turn angle which, if applied at roll stabilization, would cause the missile to just skirt the critical zone. The DTA is dependent upon the radius of the critical zone (established by a bias voltage), the value of the climb angle (CA), and the ground range from the MTR to the missile ground projection (R_M). DTA is positive if measured clockwise from the CTA line (or missile velocity line), negative if measured counterclockwise. Both +DTA and -DTA are produced in the computer. The polarity that requires the smallest turn angle is used. The ground path which skirts the bottom of area I in figure 25 is CTA + DTA. The ground path which skirts the top of area I is CTA - DTA, and represents the path the missile should follow to skirt the MTR with the smallest skirting turn angle.

70. THE SKIRTING TURN ANGLE

After the initial turn section has determined the CTA and DTA it must determine the path along which the missile should fly to just skirt the critical zone on the side closest to the Y_G line. This turn angle, called the skirting turn angle (STA), is defined as the turn angle which must be applied at roll stabilization to cause the missile ground path to just skirt the critical zone. The STA is determined by solving the equation:

$$CTA + DTA - STA \quad (30)$$

where DTA is always opposite in polarity to CTA. The relationship between CTA, DTA, and STA is shown in figure 26. The initial turn section decides whether or not a skirting turn angle is required in the following way: Whenever the CTA is a larger angle than DTA the initial turn section orders the missile to fly a zero turn angle; whenever the DTA is larger than the CTA, the initial turn section orders the missile to fly a skirting turn angle until it clears the critical zone. A simpler, more easily remembered rule is: If the polarity of the STA (the sum of CTA and DTA) is the same as the polarity of the DTA chosen, a skirting turn angle is required. As an example, suppose the MTR is situated in the center of area IV of figure 25.

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CTA = -400 mils

DTA = 100 mils.

The initial turn section will select the positive value of DTA and add it to CTA.
Thus,

$STA = -400 + (+100)$

STA = 300 mils.

STA is not of the same polarity as DTA; therefore, no skirting turn angle is required. The missile will fly a zero turn angle. Suppose the MTR is situated in the center of area II.

CTA = 50 mils

DTA = 70 mils.

The initial turn section will select the negative value of DTA and add it to CTA.
Thus,

$STA = 50 + (-70)$

STA = -20 mils.

STA is of the same polarity as DTA; therefore a skirting turn angle is required.

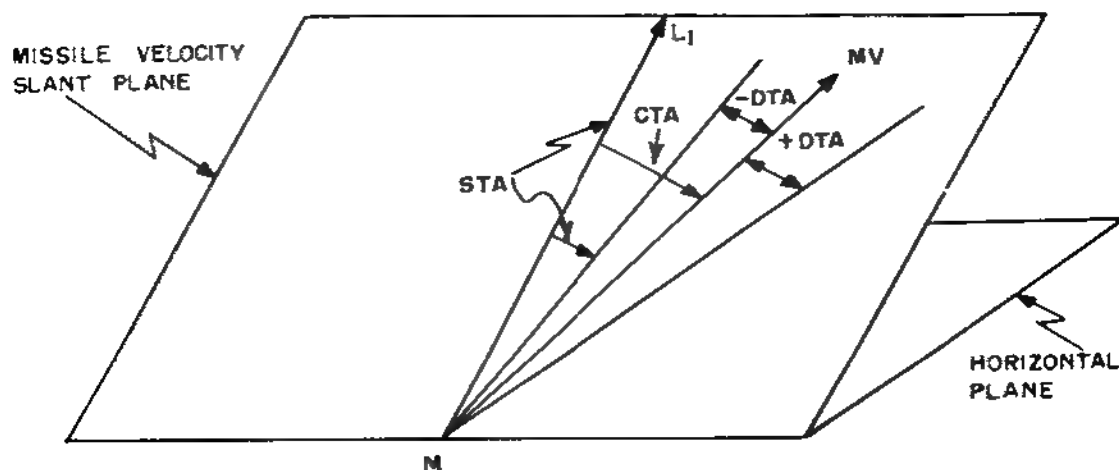


Figure 26. CTA, DTA, and STA.

Section II. INITIAL TURN SECTION BLOCK DIAGRAM

71. GENERAL

The initial turn section block diagram is found in TM 9-5000-26, page 95. The initial turn section consists of the following functional units: the missile distance converter, the critical turn angle (CTA) solver, the difference turn angle (DTA) solver, the initial turn control circuits, the turn angle reference potentiometer, the steering error converter, the fin order solver, and the radar cleared circuit. That part of the on-trajectory circuit which influences the initial turn section is also discussed.

72. INITIAL TURN SECTION OPERATION

At MISSILE AWAY the initial turn section of the computer is enabled. The section does not control the missile, however, until MISSILE AWAY + 4 (approximately 7 seconds after FIRE) at which time the missile is roll stabilized and prepared to accept orders. At MISSILE AWAY + 4 the 7g dive order circuit in the computer issues a dive order to the missile, causing it to dive toward the proper trajectory path to the target. At the same time, the initial turn section begins issuing orders which modify the dive order, causing a turning dive in the direction necessary. The dive order will be continued until the missile is on the proper $\frac{1}{2}g$ climb trajectory toward the target. Turn orders, either a skirting turn or a zero turn, will continue to be issued by the initial turn section until such time as both the ON TRAJECTORY and RADAR CLEARED signals have been received. When both ON TRAJECTORY and RADAR CLEARED signals have been received, control of the missile becomes the function of the computer steering section. The period of missile flight which is under the control of the 7g dive order circuit and the initial turn section may be considered to be a programmed flight. Steering orders issued during this period have no relationship to the steering error which may exist between the target and missile flight path, as in the steering section of the computer, but depend primarily on the relative position of the missile and the missile tracking radar.

73. MISSILE DISTANCE CONVERTER

The solution for the critical turn angle and the determination of radar cleared require that the missile position components along the X_G and Y_G axis be known. It is the function of the missile distance converter to provide this information. The operation of this circuit is identical with those circuits in the steering section which rotate steering errors from the earth coordinate axis to the gyro coordinate axis. A detailed mathematical analysis of the operation of the missile distance converter will be found in paragraphs 89b and 94b of this text. The

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outputs are X_{GM} and Y_{GM} . (The initial turn section block diagram in TV 2-5000-26, p 95, shows these as X_G and Y_G and should be corrected.) The mathematical equation for X_{GM} is:

$$X_{GM} = X_M \cos A_G - Y_M \sin A_G \quad (31)$$

for Y_{GM}

$$Y_{GM} = Y_M \cos A_G + X_M \sin A_G. \quad (32)$$

74. CRITICAL TURN ANGLE SOLVER

The critical turn angle solver has the function of determining the critical turn angle. It receives the missile distance along the X_G axis (X_{GM}), the ground range to the center of the launching area (R_G), and the missile climb angle (CA) as inputs. From this information it calculates the critical turn angle. The output is a voltage representing the critical turn angle in mils. The actual solution is an empirical solution which approximates the value of the turn angle required to cause the missile to fly over the missile-tracking radar. Since the solution is not exact, an error is introduced into the difference turn angle solution to make sure that the missile will safely skirt the critical zone around the missile tracking radar antenna.

75. DIFFERENCE TURN ANGLE SOLVER

The function of the difference turn angle solver is to produce an output which represents the difference turn angle. The unit receives as its inputs the ground range to the missile (R_M), the missile climb angle (CA), and a bias voltage. The bias voltage represents the minimum radius of the critical zone around the missile-tracking radar and introduces the necessary error required by the empirical nature of the CTA solution. The output of the unit is a voltage which represents the difference turn angle in mils.

76. INITIAL TURN CONTROL CIRCUITS

The initial turn control circuits consist of two relay amplifiers and several relays. The critical turn angle negative relay amplifier detects the polarity of the voltage representing CTA, and through relay action it selects the opposite polarity of DTA. The skirting turn angle negative relay amplifier detects the polarity of the sum of CTA and DTA, which is the skirting turn angle. Additional relay circuits make up the yes-no circuit which determines whether or not a skirting turn is required. If a skirting turn is required, proper voltages to cause this skirting turn are directed to the steering error converter. If no skirting turn is required, this fact is determined, and orders for the missile

to fly a zero turn angle trajectory are issued. Upon receipt of the RADAR CLEARED and ON TRAJECTORY signals, the initial turn control circuits disconnect the initial turn section from the steering error converter and the steering section assumes control of the missile.

77. TURN ANGLE REFERENCE

A closed loop servo system requires a feedback signal. The Nike system may be considered to be a closed loop servo. During the initial turn phase of computer operation the feedback signal is supplied by the turn angle reference circuit. The turn angle which the missile is actually flying is supplied from the turn angle reference circuit (a potentiometer in the turn angle servo) to the initial turn control circuits. In the initial turn control circuits, this turn angle is compared with the required turn angle. If these signals are not equal and opposite, an order requiring the missile to turn to the proper turn angle is directed to the steering error converter.

78. STEERING ERROR CONVERTER AND FIN ORDER SOLVER

The functions of the steering order converter and the fin order solver, during the initial turn configuration, are similar to their functions during the steering configuration. The operation of these circuits is discussed in TM 9-5000-15. The inputs to the steering error solver during the initial turn configuration, however, are the required skirting turn angle (the sum of CTA and DTA); or a zero turn angle, and the turn angle reference. From this information the required turn order is determined and sent to the fin order solver. In the fin order solver this turn order is used to modify the dive order being sent to the missile to cause the missile to execute a turning dive.

79. RADAR-CLEARED CIRCUIT

The radar-cleared circuit consists of a relay amplifier and its associated relay. The function of the circuit is to determine when the missile has safely passed the missile-tracking radar. This is required because it is desirable to bring the missile to a zero turn angle course as soon as possible after executing a skirting turn. As soon as the missile has safely skirted the critical zone the voltage representing Y_{GM} will become positive. This fact is made use of in the radar-cleared circuit to operate a relay amplifier. The negative analog is used, thus when Y_{GM} becomes positive, the voltage representing $-Y_{GM}$ becomes negative. This negative voltage causes the relay amplifier to energize its associated relay and to send the RADAR CLEARED signal to the initial turn control circuits.

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80. ON-TRAJECTORY CIRCUIT

The on-trajectory circuit is discussed in detail in TM 9-5000-15. It is shown on the block diagram of the initial turn section since the receipt of both RADAR CLEARED and ON TRAJECTORY is required before the steering section of the computer can assume control of the missile.

Section III. SIMPLIFIED FUNCTIONAL OPERATION

81. REFERENCES

The initial turn functional schematic is shown in TM 9-5000-26, page 96. All coordinate references refer to page 96 TM 9-5000-26.

82. THE CTA AMPLIFIER CIRCUIT

The CTA amplifier circuit consists of the DC amplifier labeled CTA (96A3) and its associated input and feedback networks. The CTA amplifier solves for the correct polarity and value of CTA. The voltage input to the CTA amplifier circuit is X_{GM} (96A2), marked X_G on the schematic. The other two inputs to the CTA amplifier circuit are mechanical. One of these inputs is R_G , which represents the handsetting of the LAUNCHER FROM TARGET RADAR RANGE PARALLAX potentiometer (96B3) which is in the feedback network of the CTA amplifier circuit. The other mechanical input is CA, the position of the brush arm on the potentiometer, CA2-4.25 (96B3). When the polarity of the voltage which represents X_{GM} is negative, the output of the CTA amplifier circuit is a positive voltage. A positive CTA is represented by a positive voltage. The output of the CTA amplifier circuit is applied to the CTA negative relay amplifier (96B4), the turn angle zero relay (96A5), and the STA negative relay amplifier (96B5).

83. THE CTA NEGATIVE RELAY AMPLIFIER CIRCUIT

The CTA negative relay amplifier circuit consists of a relay amplifier (96B4) and its associated relays. The output of the CTA negative relay amplifier circuit may be considered as mechanical, because the operation of the circuit determines the position of relay contacts. When the input to the CTA negative relay amplifier circuit is negative, the relay amplifier causes its associated relays to be energized. If the input is positive, the relays are not energized. One set of contacts (6, 5, and 11) is located in the +DTA and -DTA amplifier circuit. Another set of contacts (3, 4, and 10) is located in the yes-no circuit.

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84. THE +DTA AND -DTA AMPLIFIER CIRCUIT

The +DTA and -DTA amplifier circuit consists of two DC amplifiers labeled +DTA and -DTA (96B3 and 96C4) and their associated input and feedback nets. The +DTA and -DTA amplifier circuit solves for the correct value of DTA and produces an output voltage which represents that DTA. The inputs to this circuit are the voltage, R_M , the position (CA) of the brush arm on potentiometer CA2-3.75, and the position of the contact of the CRITICAL TURN ANGLE NEGATIVE relay (96B4). Refer to figure 25. Suppose the MTR is located in area IV. Then the initial turn section will compute a negative value of CTA. This negative value of CTA will cause the CTA negative relay amplifier to energize the CTA negative relays (96B4). Meanwhile the DTA has been computed by the +DTA and -DTA amplifier circuit. The DTA is actually computed by the +DTA amplifier. The -DTA amplifier inverts the output of the +DTA amplifier. From figure 25 it appears that the proper ground path of the missile will result when the positive value of DTA is added to the CTA. The energizing of the CTA negative relay (96B4) results in the selection of the positive value of DTA as the value to be added to the CTA. This positive value of DTA is applied to two locations: the turn angle zero relay (96B6) and the STA negative relay amplifier (96B5).

85. YES-NO CIRCUIT

The yes-no circuit consists of contacts 3, 4, and 11 of the CTA negative relay, K105 (96C4); contacts 3, 4, and 5 of the STA negative relay, K108 (96C5), and the turn angle zero relay, K121 (96C6). The yes no circuit provides the answer to the question, should the missile fly with an initial turn angle of zero mils? The answer to this question is dependent upon the position of the contacts of the CTA negative and STA negative relays. Whenever both relays are energized at the same time or deenergized at the same time, the answer is YES. Refer again to figure 25. Suppose the MTR is again in the center of area IV. As stated in paragraph 84 above, the CTA negative relay is energized (CTA negative) and the positive value of DTA has been selected. At the input to the STA negative relay amplifier +DTA is added to CTA. When the resultant input to the STA negative relay amplifier is negative, the STA negative relay is energized. When the MTR is in the center of area IV, the value of CTA will be larger than the value of DTA. Hence the resultant input to the STA negative relay amplifier is negative and therefore the STA negative relay is energized. It would appear from figure 25 that if the MTR were located in the center of area IV, the missile should fly with an initial turn angle of 0°. Since both the CTA and STA negative relays are energized at the same time, the answer given by the yes-no circuit is YES, the missile should fly with an initial turn angle of 0°. Whenever the answer is yes, the turn angle zero relay (96C6) is energized. Suppose that the position of the MTR in figure 25 is in the center of area II.

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Then from the illustrative problem in paragraph 70, CTA is positive and smaller in value than DTA. The proper ground path will result when the negative value of DTA is added to CTA. Since the polarity of that DTA which should be selected is the same as the resultant polarity of STA, a skirting turn is required. Under the conditions of the illustrative problem, the initial turn circuits will perform as follows: The output of the CTA amplifier circuit will be positive; the CTA negative relay will be deenergized; as a result, the negative value of DTA will be selected as the output of the +DTA and -DTA amplifier circuit. Since DTA is greater in value than CTA, the resultant input voltage to the STA negative relay amplifier will be negative. Therefore, the STA negative relay will be energized. Since the CTA negative relay is deenergized, the answer provided by the yes-no circuit is NO; therefore the missile should not fly with an initial turn angle of zero mils. This is indicated by the turn angle zero relay which is deenergized.

86. INITIAL TURN ANGLE FEEDBACK POTENTIOMETER

a. General. The initial turn angle feedback potentiometer (TA4-3.75) completes the loop in the closed-loop control system which contains the missile. This control loop establishes and maintains the turn angle which the missile should fly from roll stabilization until RADAR CLEARED and ON TRAJECTORY. The potentiometer is shown at 96C6. Figure 27 may facilitate an understanding of the importance of this potentiometer in the functional operation of the initial turn section. Figure 27 is a block diagram of the closed-loop control system which establishes and maintains after roll stabilization either a zero turn angle or the STA computed by the initial turn section. The brush arm of the initial turn angle feedback potentiometer is driven by the output shaft of the TA servo. The voltage tapped off the potentiometer is a feedback function of the controlled variable (TA). This voltage is applied to the comparator (S_T amplifier) where it is compared with the reference input voltage. The reference input voltage will be zero if the yes-no circuit in the initial turn circuit gives an answer of YES. If the answer given by the yes-no circuit is NO, the reference input will be the algebraic sum of CTA and the DTA voltage chosen by the initial turn section. (This voltage is equivalent to STA.) The reference input voltage always has a polarity that is opposite to the feedback voltage. If the feedback voltage is not equal to the reference input voltage, the output of the comparator is an error voltage. This error voltage is converted to a fin order which causes the missile to change its flight path so as to reduce the error. As the flight path changes, the missile turn angle changes, and consequently the position of the TA servo output shaft. When the output shaft of the TA servo drives the brush arm of the initial turn angle feedback potentiometer to a position at which the feedback voltage is equal in magnitude to the reference input, the error voltage becomes zero.

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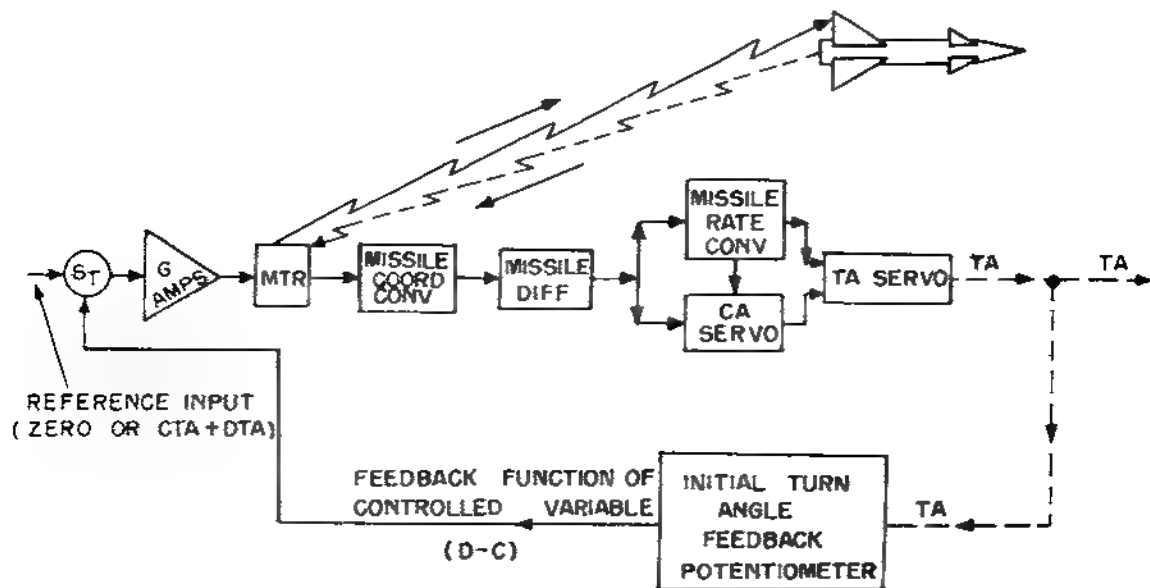


Figure 27. Closed-loop control circuit for establishing and maintaining the initial turn angle.

b. Turn angle zero. Suppose the yes-no circuit has responded with a YES answer. The turn angle zero relay will be energized and a ground potential will appear at terminals 4 and 5 (96B7) of the $-S_T$ input network. Therefore, the reference input voltage is zero. In paragraph 68 it is pointed out that at roll stabilization the initial turn angle will usually be of some value other than zero mils. Therefore, the shaft of the TA servo will be at some position other than zero. A voltage other than zero will be tapped off by the brush arm of TA4-3.75 (initial turn angle feedback potentiometer) and applied to terminal 3 of the $-S_T$ amplifier. Consequently, the S_T amplifier will produce an error voltage which will result in a modification of the 7g dive order so that the missile executes a turning dive in a direction which will reduce the turn angle. The missile coordinate converter produces voltages which represent the missile position. The missile rate converter receives these voltages which represent the components of missile velocity along axes in the missile velocity slant plane. The TA servo receives the latter voltages and solves for the turn angle (TA). As the missile executes the turning dive, the subsequent changes of voltages in the computer lead to a change in the shaft position of the TA servo and consequently a change in the voltage fed back to the $-S_T$ amplifier. When the missile turn angle is zero mils, the shaft of the TA servo will be in its zero position, the input to terminal 3 of the $-S_T$ input network will be zero, and the error voltage will be zero. Therefore, modification of the 7g dive order ceases and the missile continues to dive until the ON TRAJECTORY signal is received.

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c. Turn angle not zero. Suppose the yes-no circuit has responded with a NO answer. The turn angle zero relay will be deenergized and the algebraic sum of the voltages which appear at terminals 4 and 5 of the $-S_T$ input network is the voltage equivalent of STA. This voltage is the reference input voltage, and it remains constant in magnitude and polarity after roll stabilization. Since an initial turn angle will exist at roll stabilization, a voltage other than zero will be tapped off TA3-3.75 and will appear at terminal 3 of the $-S_T$ input network. If the voltage at terminal 3 is different from the voltage equivalent of STA, the S_T amplifier produces an error voltage. This error voltage, when applied to the G_Y and G_P amplifier, results in a fin order which modifies the 7g dive order. The missile is ordered to execute a turning dive in the direction ordered by the error voltage. As the turning dive takes place, the voltages that represent missile position and velocity, change; therefore, the voltages that represent the components of missile velocity in the missile velocity slant plane, change. As a consequence of the foregoing changes, the output of the TA servo, the feedback voltage, and the error voltage all changes. When the feedback voltage is equal to voltage equivalent of STA, the shaft of the TA servo will be positioned to a turn angle equal to the STA, and the missile will fly with a turn angle equal to STA. As the missile continues to dive, the missile turn angle will tend to change; however, any change in the turn angle will result in a change in the output of the TA servo. Such a change will result in an error voltage which will cause the missile to return to the desired skirting turn angle. In this manner, once the proper STA has been established, the closed loop control circuit makes sure that the missile is guided with a turn angle equal to the STA until the missile is safely beyond the MTR (RADAR CLEARED signal is received). After RADAR CLEARED, the zero turn angle relay, K121, is energized, and the closed loop control circuit performs like that of the zero turn angle.

87. RADAR CLEARED RELAY AMPLIFIER CIRCUIT

The radar cleared relay amplifier circuit consists of a relay amplifier and its associated relay. The input voltage is $-Y_{GM}$. The quantity, Y_{GM} , is the distance along the Y_G axis from the MTR to the ground projection of the missile. If the $-Y_{GM}$ voltage is negative, the radar-cleared relay will be energized by the action of the relay amplifier (96C5). Refer to figure 25. If the MTR is on the side of the launcher away from the intercept point, Y_{GM} is positive. Hence, the $-Y_{GM}$ voltage is negative and the radar-cleared relay is energized. If the MTR is between the launcher and the intercept point, Y_{GM} is negative until the missile passes by the MTR, at which time it becomes positive. Therefore, if the MTR is between the launcher and the intercept point, the voltage, $-Y_{GM}$, is positive until the missile passes by the MTR, at which time it becomes negative. One output of the radar-cleared relay amplifier circuit is the position of contacts 4, 5, and 6 of the radar-cleared relay. These contacts

affect the operation of the turn angle zero relay. When the radar cleared relay is energized, one of its contacts provides a ground for the turn angle zero relay, and thus causes it to become energized. The significance of the previous statement is that when the RADAR CLEARED signal is received (Y_{GM} first becomes positive) the yes-no circuit provides a YES answer. From figure 25, if the MTR is to the left of the X_G axis, the missile should fly with an initial turn angle of zero mils. In the initial turn section, if the MTR is to the left of the X_G axis, Y_{GM} is positive, the voltage $-Y_{GM}$ is negative, the radar-cleared relay is energized, and the response of the yes no circuit is YES, because the turn angle zero relay is held energized by the closed contacts of the radar-cleared relay. Whenever the missile is in flight, the X_G and Y_G axes can be considered as being attached to the missile. Thus, in figure 25, if the MTR is between the launcher and the target, the MTR is to the right of the X_G axis. When the missile has passed by the MTR, the MTR will be to the left of the X_G axis; consequently the radar-cleared relay will be energized (RADAR CLEARED signal is received) and the response of the yes-no circuit becomes YES, regardless of what it was before.

88. INITIAL TURN RELAY

The initial portion of the steering phase in the computer is completed when the initial turn relays (96C6 and 96C7) are deenergized. The initial turn relays are always energized until the RADAR CLEARED and ON TRAJECTORY signals have been received. Energizing the radar-cleared relay constitutes the RADAR CLEARED signal. Energizing the on-trajectory locking relay constitutes the ON TRAJECTORY signal. The contact of the on-trajectory locking relay is shown at 96C6. The contact of the radar-cleared relay is shown at 96C5. At the instant the initial turn relay becomes deenergized, the output, or outputs, from the initial turn section are removed from the input terminals of the $-S_T$ amplifier and the inputs derived from the steering section of the computer are substituted.

Section IV. DETAILED FUNCTIONAL OPERATION

89. CTA AMPLIFIER AND ASSOCIATED NETWORKS

a. References. In this discussion and in the discussions to follow, the schematics in TM 9-5000-26, pages 97 through 102, will be used as the primary reference. The CTA amplifier, with its input and feedback networks, is shown in TM 9-5000-26, page 97.

b. General. The feedback network of the CTA amplifier circuit is composed of the potentiometer, CA2-4.25, and the range parallax potentiometer,

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R15. The potentiometer, CA2-4.25, is in the climb and turn angle servo assembly. The range parallax potentiometer, R15, is located in the upper right corner of the computer control panel. A more detailed schematic of this potentiometer is in TM 9-5000-26, page 101. The voltage input to the CTA amplifier is X_{GM} . The mechanical inputs (R_G) are the position of the handset potentiometer, R15, and the position of the brush arm of the potentiometer, CA2 4.25. The output of the CTA amplifier is a voltage which represents the CTA. The scale factor of this voltage is such that 0.05 volt is equivalent to 1 angular mil. The switch associated with the potentiometer, R15, is positioned to the value which most nearly approximates the actual distance from the launching area to the battery control area.

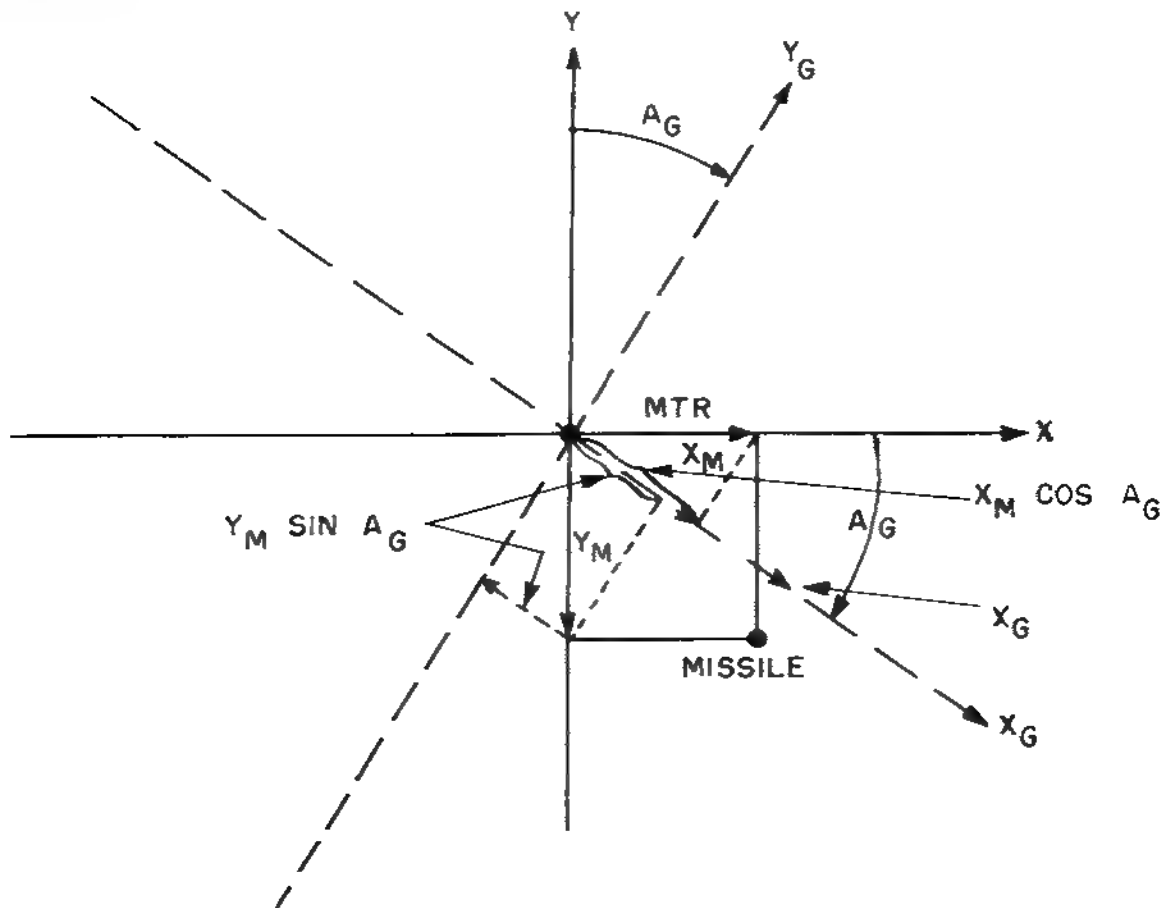


Figure 28. Graphical determination of X_{GM} .

c. Mathematical analysis. Figure 28 gives a picture of the determination of X_{GM} . This is done by converting the rectangular earth coordinates of the missile (X_M , Y_M) to the coordinate along the X_G axis. The projection of the

distance, X_M , on the X_G axis is

$$X_M \cos A_G \quad (33)$$

and the projection of the Y_M distance on the X_G axis is

$$Y_M \sin A_G. \quad (34)$$

The algebraic expression for X_{GM} is

$$X_{GM} = X_M \cos A_G - Y_M \sin A_G. \quad (35)$$

d. Detailed functional operation. The voltages, $+X_M$ and $-X_M$, are applied to the potentiometer, A_G-7 ; and the voltages, $+Y_M$ and $-Y_M$, are applied to the potentiometer, A_G-6 . These are shown at 97A1 and 97B1. The voltage, $X_M \cos A_G$, is brought into the input network on terminal 3 (97A5). The voltage, $-Y_M \sin A_G$, is brought into the input network on terminal 4. The algebraic sum of these voltages is equal to X_{GM} . In any amplifier the output voltage is dependent upon the input voltage and upon the gain of the amplifier. The gain of any feedback amplifier is, in turn, dependent upon the amount of voltage fed back to the input terminals. In the CTA amplifier the output voltage (CTA) is made to depend upon X_{GM} , R_G , and CA, first by applying as an input voltage the X_{GM} voltage, and second by varying the resistive values in the feedback network in accordance with the values of R_G and CA. The required values of the elements in the feedback network were determined by the design engineers on the basis of experimental and calculated data obtained from the performance characteristics of the missile. The CTA is continuously calculated in the CTA amplifier from MISSILE AWAY to the time of roll stabilization (MISSILE AWAY + 4). As a result, the capacitor, C169, is charged to the value of CTA. The energizing of RS1 (the roll stabilization relay, K179) at MISSILE AWAY + 4 removes the input voltage to the CTA amplifier and shunts C169 by C178, placing on the two capacitors the charge which was placed upon C169 alone before roll stabilization, consequently after roll stabilization, the output voltage (CTA) is held almost constant long enough to permit satisfactory operation of the initial turn section. The limits of CA and range parallax (R_G) are shown on the schematic at 97C7 and 97C5 (1,867 to 1,333 mils for CA, and 1,000 to 6,000 yards for R_G). The CTA limiter limits the output voltage to ± 25 volts, which is equivalent to 500 mils.

e. Handsetting the range parallax potentiometer. During orientation and synchronization of the Nike I system, the X- and Y-coordinates of target radar to launcher parallax are determined quite accurately by survey or other means. These quantities are X_L and Y_L . The value of R_G which should be handset on R15 is calculated by the following formula:

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$$R_G = \sqrt{X_L^2 + Y_L^2} . \quad (36)$$

Once the setting of R15 has been made, it will not be necessary to change it unless the components of the Nike system are moved to new locations.

90. CTA NEGATIVE RELAY AMPLIFIER

a. General. The CTA negative relay amplifier (98D6) is of the type discussed in paragraph 95, below. An input of 10 millivolts (-0.01 volt) will cause the relay amplifier to energize the CTA negative relay. That is, when the output of the CTA amplifier is a negative voltage which represents 1 or more angular mils, the application of this signal as the input to the CTA negative relay amplifier will result in the energizing of the relays, K104 and K105 (96D8).

b. Relay action. Suppose CTA is negative. Before roll stabilization, the contacts of deenergized relay K102 complete the output circuit of the CTA negative relay amplifier and K104 is energized. Thus a ground is provided for K105 by the contacts 3 and 2 of K104. Consequently, K105 is energized, the contacts 1 and 3 of K102 are shunted by the closed contacts 2 and 9 of K105, and K104 remains energized, even after roll stabilization. Additional contacts of K105 are shown at 96B6 and at 108D7. The contacts at 96B6 are common to the output circuits of the +DTA and -DTA amplifiers. The contacts at 108D7 are in the yes-no circuit.

91. THE +DTA AND -DTA AMPLIFIER CIRCUITS

a. General. The +DTA and -DTA amplifiers produce voltage outputs which represent +DTA and -DTA. The input voltage to the +DTA amplifier is a function of R_M and CA. The output is a voltage which represents the positive value of DTA. The two inputs to the +DTA amplifier input circuit are R_M (98A9) and the mechanical input, CA, which is the position of the brush arm of the potentiometer, CA2-3.75. The scale factor of the output is 0.05 volt per angular mil, and the output is always a positive voltage. The -DTA amplifier is a simple inversion amplifier which reproduces +DTA, but of the opposite sign.

b. Detailed operation of the input circuits. The voltage, R_M , from the missile coordinate converter is brought into the servo cabinet on terminal 547 (98A10) where it appears across the voltage divider in the ballistic resistor panel. A potential of -250 volts is brought into the ballistic resistor panel on J1-14. The potential at J1-10 of the ballistic resistor panel appears across the potentiometer, CA2-3.75. The voltage tapped off this potentiometer by the brush arm is brought to terminal 3 of the +DTA input network (98A12). The value of this voltage for any position of the brush arm of CA2-3.75, and any value of R_M , is given by the expression:

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$$\text{Voltage at terminal 3} = \frac{(2,045 - CA)}{712} (0.168R_M - 0.999) \text{ volts.} \quad (37)$$

As an example of the use of this expression, suppose that

CA = 1,333 mils and R_M = 1,000 yards, or 1 volt.

$$\text{Then the voltage at terminal 3} = \frac{(2,045 - 1,333)}{712} (0.168 - 0.999)$$

$$\frac{712}{712} \times -0.861$$

$$= -0.861 \text{ volt.}$$

Suppose CA is 2,045 mils. The schematic diagram shows the brush arm of CA2-3.75 at ground potential, hence the voltage at terminal 3 of the +DTA input network is zero. Substitution of the value of CA in the expression above will yield the same result. It is stated in paragraph 69b that in computing the CTA, the error in using the TTR to launcher range parallax instead of the distance from the MTR to the missile is compensated for in the +DTA and -DTA amplifier circuits. The proper design of the input network to the +DTA amplifier provides this compensation. The potential which appears at J1 11 of the ballistic resistor panel is brought into the +DTA input network on terminal 4. The value of this voltage is 0.422 volt, which represents the shortest MTR-to-missile ground range allowable at the time the missile passes by the critical zone. The gain of the +DTA amplifier is determined by the relative values of the resistors in the feedback network. The gain is

$$\frac{106,430}{6,430} = 16.55.$$

The output of the +DTA amplifier, when the voltage at terminal 3 is zero, is determined by multiplying the input voltage at terminal 4 by the gain of the amplifier. Thus:

$$\text{Minimum DTA voltage} = (-0.422) \times (-16.55)$$

$$6.99 \text{ volts.}$$

and since the scale factor is 0.05 volt per mil the

$$\text{minimum DTA angle is } \frac{6.99}{0.05} = 139 \text{ mils.}$$

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c. Detailed operation of the +DTA and -DTA amplifiers. The DTA is continuously calculated in the +DTA amplifier from MISSILE AWAY to the time of roll stabilization (MISSILE AWAY + 4). At MISSILE AWAY, energizing the missile away locking relay, K5 (98A9), completes the circuit between the +R_M amplifier and the voltage divider in the ballistic resistor panel. As a result the capacitor, C176 (98A13), is charged to the value of +DTA. Energizing the roll stabilization relay, RS1 (K179), at MISSILE AWAY + 4, results in the removal of the input voltage to the +DTA amplifier and in shunting C176 by C179, placing on the two capacitors the charge which was placed upon C176 alone before roll stabilization. As a result of the increased capacitance, the output voltage is held almost constant long enough to permit satisfactory operation of the initial turn section. The limits of the mechanical input, CA, are 1,333 mils to 2,045 mils. The -DTA amplifier is a copying and inverting amplifier. It has a gain of unity and produces the negative value of DTA.

d. Detailed functional operation of the output circuit. The selection of the polarity of the DTA to be produced as an output by the +DTA and -DTA amplifier circuits is determined by the polarity of CTA. Contacts of the CTA negative relay, K105, are placed in the output circuits of the +DTA and -DTA amplifiers. This relay is energized only when CTA is negative. The output of the +DTA amplifier is chosen when the relay is energized. The output of the -DTA amplifier is chosen when the relay, K105, is deenergized.

92. YES-NO CIRCUIT

a. General. The components of the yes-no circuit are listed in paragraph 85. To the question, should the missile fly with an initial turn angle of zero mils, the yes-no circuit operates to provide a YES or NO answer.

b. STA negative relay amplifier. The STA negative relay amplifier (98B15) is identical to the CTA relay amplifier. The inputs to this amplifier are CTA and DTA. Whenever the algebraic sum of the voltages representing CTA and DTA is negative and equal to or greater than 0.01 volt, the current in the output circuit of the STA negative relay amplifier will be sufficient to energize the STA negative relay, K108. This indicates that when the STA is equal to or greater than -1/5 mil, the STA negative relay is energized. Before roll stabilization, the roll stabilization delay relay, K107, is energized and contacts 4 and 5 (98B16) provide a path for current flow in the output circuit. The roll stabilization delay relay, K107, is energized prior to MISSILE AWAY + 4. It is a delay relay, and although it is deenergized at MISSILE AWAY + 4, its contact will not open until after a short delay. The STA negative delay, K108, however, if energized before roll stabilization, remains energized, since a path to ground is provided both through contacts 6 and 8 of K107 and contacts 2 and 3 of K108.

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c. Relay action. In paragraph 85, it is stated that for an MTR position in the center of area II as shown in figure 25, the response of the yes-no circuit should be NO. Refer to TM 9-5000-26, page 108. Since CTA is positive, K105 (108D6) is deenergized. The negative value of DTA has been selected as the other input to the STA amplifier. Since the DTA is greater than the CTA, the STA is negative; therefore, the action of the STA negative relay amplifier (108D4) causes K108 to be energized. Refer to the contacts of K105 and K108 shown at 108A7, and to the drawing of K121 at 108A8. If K108 is energized and K105 deenergized, no ground path is provided for current flow from the 28 volt source through the coil of K121; hence K121 is deenergized, and the response of the yes-no circuit is NO. Refer to the contacts of K121 shown at 98C13. The DTA is brought into contact 1 of K121, and the CTA is brought into contact 6 of K121. If K121 is deenergized, a path for DTA is provided from contact 1 through contact 3 to the input circuit of the S_T amplifier, and a path for CTA is provided from contact 6 through contact 4 to the input circuit of the S_T amplifier.

93. ESTABLISHMENT OF INITIAL TURN AFTER ROLL STABILIZATION

a. General. The initial turn angle at which the missile is ordered to fly after roll stabilization is established and maintained by a closed loop control system which controls the TA established by the shaft of the TA servo. The feedback element in this closed loop control system is the initial turn angle feedback potentiometer. The reference input voltage is the algebraic sum of the voltages which appear at contacts 3 and 4 of the turn angle zero relay, K121 (98C13). If the relay is energized, the reference input voltage is zero. If the relay is deenergized, the reference input is STA.

b. Initial turn angle feedback potentiometer. The initial turn angle feedback potentiometer, TA4-3.75, is shown at 98C11. The feedback voltage, which is compared with the reference input, is tapped off this potentiometer. As shown on the schematic, -250 volts is brought into the climb and turn angle servo assembly on J3-T, and +250 volts is brought in on J3-R. The 250-volt potential appears at the +2,500 mil limit of the card. The +250-volt potential appears at the -2,500 mil limit of the card. When the TA is zero degrees, the brush arm of the potentiometer will be at zero potential. The scale factor of the voltage which appears at J121-3 is 0.1 volt per angular mil. By placing a 0.499-megohm resistor (10C13) in series with the 0.5-megohm input resistor in the S_T input network, the scale factor of the voltage from TA4-3.75 is made equal to the scale factor for CTA and DTA. Suppose the initial turn angle at the end of roll stabilization is 200 mils. The brush arm of TA4-3.75 will be positioned at the +200-mil point on the card, and the potential at J121-3 will be 20 volts. This voltage, when applied to the fin order solver, will cause the missile to make a hard left turn instead of a pure dive. Since the initial turn angle was initially positive, the left turn decreases the turn angle and thus causes the potential at

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J121 3 to decrease. As the missile continues to turn to the left, the TA becomes negative and the voltage at J121 3 becomes positive. But a positive voltage will cause the missile to turn to the right until the potential at J121-3 becomes zero at which time the missile continues in a pure dive. Suppose the following conditions exist at MISSILE AWAY + 4:

K121 energized (98C13)
DTA is +4 volts (80 mils)
CTA is -1 volt (20 mils)
TA is 4 volts (40 mils).

The turn angle at which the missile should fly is 60 mils and the turn angle which exists is 40 mils. It appears from the values given above that the algebraic sum of these voltages is 1 volt. However, the summing of these voltages does not actually take place until after their application to the $-S_T$ amplifier. Since the scale factor of the TA voltage at J121-3 is twice as great as the scale factor of the other two voltages, the TA voltage must be weighted by a factor of one half in the $-S_T$ amplifier in order to maintain at the output of the $-S_T$ amplifier a scale factor which is the same for all three voltages. The input to S_T amplifier therefore is -2 volts. Thus the effective input at the $-S_T$ amplifier is +1 volt. This positive voltage will cause the missile to turn to the right enough to cause the turn angle to increase from 40 mils to 60 mils. When the brush arm of 1A4-3.75 is positioned to 60 mils, the potential at J121 3 is 6 volts, and the effective input to the $-S_T$ amplifier, due to this source, is one-half of 6 volts, or 3 volts. This voltage cancels the +3 volts which represents the STA, and the output of the $-S_T$ amplifier is zero. The missile continues to dive, but the feedback action of TA4-3.75 forces it to maintain the turn angle constant at 60 mils.

94. RADAR-CLEARED CIRCUIT

a. General. The radar cleared circuit produces the RADAR CLEARED signal. The input to this circuit is the quantity, Y_{GM} , which is the algebraic sum of two voltages. The output is the mechanical position of the contacts of the radar cleared relay, K109.

b. Mathematical analysis. Figure 29 shows how Y_{GM} is determined graphically by converting the rectangular earth coordinates of the missile (X_M , Y_M) to the coordinate along the Y_G axis. The projection of distance X_M on the Y_G axis is:

$$X_M \sin A_G \quad (38)$$

and the projection of distance Y_M on the Y_G axis is:

$$Y_M \cos A_G. \quad (39)$$

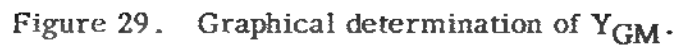
The algebraic expression for Y_{GM} is:

$$Y_{GM} = X_M \sin A_G + Y_M \cos A_G. \quad (40)$$

c. Detailed functional operation. It should be apparent from figure 29 that Y_{GM} is negative before the missile passes by the MTR. The relay amplifier operates the radar-cleared relay when the input signal is -10 millivolts. However, RADAR CLEARED is sent only when Y_{GM} becomes positive. Therefore, for proper operation the computer voltages which represent Y_{GM} must be:

$$(-X_M \sin A_G) + (Y_M \cos A_G). \quad (41)$$

The voltage, $X_M \sin A_G$, enters the computer amplifier cabinet at terminal 287 (97A3) and is applied to P1 2 of the radar-cleared relay amplifier (98B15). The voltage, $-Y_M \cos A_G$ enters the computer amplifier cabinet at terminal 288 (97B3) and is brought into P1 3 of the radar-cleared relay amplifier (98C15). These voltages are shown as $+Y_G-1$ and $+Y_G-2$, and the algebraic sum is representative of $-Y_{GM}$. When the missile is 10 yards past the MTR ($Y_{GM} +10$ yards), the algebraic sum of the voltage inputs to the radar-cleared relay amplifier is -10 millivolts. This value causes the radar-cleared relay amplifier to draw enough current through K109 to energize the relay. This produces the RADAR CLEARED signal. Refer to TM 9-5000-26, page 108. When K109 is energized, a path is provided from the 28 volt supply (108A8) through the coil of K121 and through contacts 5 and 4 of K109 to ground (108A7). Therefore, K121, the turn angle zero relay, is energized. If the K121 relay was previously deenergized (missile flying with an STA), the energizing of K121 by the action of the radar cleared relay causes the skirting turn order to be removed from the missile. At this time the missile is turned until the turn angle is zero and then continues to fly at a zero mil turn angle until the ON TRAJECTORY signal is received. Contacts 4 and 6 of K109 (108A7) and contacts 4 and 6 of K4 (the ON TRAJECTORY relay) provide a double ground which insures that the initial turn relays remain energized until K109 and K4 are both energized (RADAR CLEARED and ON TRAJECTORY signals received). Steering orders from the steering error converter are applied to the fin order solver only when K124 and K125 are deenergized.



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same polarity. In any case when the resultant input signal at the grid of the first stage goes negative, the relay becomes energized. When the signal goes positive, the relay becomes deenergized. An adjustment, marked BALANCE CIRCUIT, is provided to insure that the associated relay will respond correctly to the input signals.

96. DETAILED CIRCUIT OPERATION

a. General. The detailed schematic of the relay amplifier appears in TM 9-5000-26, page 94. In the discussion of this circuit, the operation of the input circuit, stage V1, stage V2, and the associated relay will be considered.

b. Input circuit. The input circuit of the GS-15706 relay amplifier consists of R1 and R2. These are balanced resistors which sum the input signals appearing at P1-2 and P1-3 and apply the sum signal to pin 3 of V1. Test points TP₁ and TP₂ are provided so that maintenance personnel may monitor the input signals.

c. Operation of V1. Tube V1 is a high μ twin triode tube (JAN 5755) which was especially designed for use as the first stage of the computer d-c amplifier. Because of its stability and low drift characteristics, it is equally well suited for use as the first stage of the relay amplifier. To simplify the explanation of the operation of V1, V1A can be considered as a cathode follower and V1B as a grounded grid triode. The signal applied at pin 3 of V1A appears at the cathode without inversion and is applied to pin 7 of V1B. In V1B, no inversion takes place since the signal is injected at the cathode. The signal appearing at pin 8 of V1B is in phase with the input signal at pin 3 of V1B but is slightly amplified. Actually V1 is a cathode coupled amplifier, and since the cathode resistor, R6, is common to V1A and V1B, and since the grid of V1B is held at a constant potential, an appreciable voltage change at the cathode of V1A cannot occur. The over-all effect is a switching of the space current in the two tube sections. For example, a negative signal at the grid of V1A will cause the space current in V1A to decrease. Less current flow through V1A will cause an increased current flow through V1B. The potential at the plate of V1B will drop, and this drop is coupled to V2A. Resistances R3 and R4 form a voltage divider in the plate circuit of V1A which reduces the plate potential of this stage to the correct operating point. Resistance R5 is the plate load resistor for V1B. Switch S1 is provided to permit grounding the input to the stage during adjustment procedures. (See TM 9-5000-23 for adjustment procedure.) Resistances R13, R14, R15, R16, and R17 form a voltage divider and balance circuit which permits adjustment of the grid potential of V1B for proper operation.

d. Operation of V2. The signal at the plate of V1B is coupled to the grid of V2A through a voltage divider composed of R8 and R9. These resistors reduce

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the signal level by a factor of 0.67. C1 provides a high-frequency ground to prevent transients from affecting the operation of the relay. V2A is a voltage amplifier. The signal applied to the grid, pin 2, is amplified and inverted, and appears at the plate, pin 1. The signal from pin 1 is coupled to the grid of V2B through the voltage divider composed of R12 and R11. These resistors reduce the signal level, again by a factor of 0.67. Tube V2B is a power amplifier which supplies sufficient power to operate the associated relay. The signal appearing at the grid, pin 7, is amplified and inverted, and appears at pin 6. It should be noted that although inversion occurs within the relay amplifier, the voltage signal appearing at P1 8 is in phase with the sum signal at V1, pin 3. R7 is the plate load resistor for V2A. Resistors R7, R11, and R12 also form a voltage divider between +250 volts and -250 volts, which sets the operating point for V2B. Resistor R10, the common cathode resistor for V2A and V2B, supplies some regenerative feedback within the stage.

e. Relay operation. The relay associated with the relay amplifier, marked K on the schematic, is a current relay. When a current of 8 milliamperes flows through the relay it will energize. When this current decreases to 2 milliamperes, the relay deenergizes. The relay and its associated 10,000 ohm resistor form the plate load for V2B. When the voltage signal appearing at the plate of V2B goes negative, the current flow through the relay must increase. When it increases to the proper value, the relay energizes. If the circuit is properly adjusted, this current flow will be caused by an input signal of 10 millivolts; +10 millivolts will cause the relay to deenergize.

APPENDIX I

COMPUTER CONDITIONING AND SEQUENTIAL SWITCHING

1. GENERAL

This appendix describes, in tabular form, the computer conditioning and sequential switching under the control of the COMPUTER CONDITION switch and the computer control circuits. The computer control circuits are shown schematically in section VI of TM 9-5000-26. The sequence of events for the Nike I computer is shown graphically in figure 1 of this appendix.

2. COMPUTER CONDITIONING

Computer conditioning is under the control of the COMPUTER CONDITION switch on the computer control panel. The positions of this switch, with the corresponding computer conditions are as follows in table I.

Table I. COMPUTER CONDITION switch operation.

<u>Position</u>	<u>Condition</u>
1. ACTION	When the COMPUTER CONDITION switch is first thrown to ACTION, the computer is essentially in the STANDBY condition. That is, the A_G servo is positioned in the direction of the expected attack by the GYRO AZIMUTH 100'S MILS switch and the time-of-flight predictor and ballistic elevation servo are positioned to the standby values. All differentiators are disabled, with the $+H_M$ having a synthetic end-of-boost velocity input. The climb angle and turn angle servos are positioned by this end-of-boost velocity input to 1,600 mils and 0 mils, respectively. The computer is in the prelaunch configuration. The $+S$ -voltage supply is connected to the target and missile range data potentiometers. The 120-volt, 400 cycle voltage is applied to all computer circuits. Circuits that will subsequently do sequential switching are enabled. The second-per-second bias network in the t -servo is enabled. Launcher parallax potentiometers are connected to the intercept-point solver.

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Table I. COMPUTER CONDITION switch operation (cont).

<u>Position</u>	<u>Condition</u>
1. ACTION (cont)	Target position data is made available to the intercept-point solver, but is not connected. Steering order outputs of the computer are disconnected from the missile-tracking radar. The burst order circuit is partially enabled, but not connected through to the missile-tracking radar. The $-H_M$ amplifier is conditioned for the missile-away circuit. The 120-volt, 400-cycle voltage is applied to all servos, plotting boards, and computer circuits.
2. STANDBY	The computer is in the prelaunch configuration. The A_G servo is positioned in the direction of expected attack by synthetic voltage inputs from the GYRO AZIMUTH 100'S MILS switch. The time-of-flight predictor is positioned to 44.57 seconds. The ballistic elevation servo is positioned to -565 mils. The target and missile differentiators are disabled, and the $+H_M$ amplifier has a synthetic end-of-boost velocity input positions the climb angle servo to 1,600 mils and the turn angle servo to 0 mils. The $+S$ -voltage supply is disconnected from the target and missile range data potentiometers. The 120-volt, 400-cycle voltage is applied to all computer circuits, unless the cycle timer modification has been made. If this modification has been made, excitation is removed from the computer servos after the first 9.5 minutes.
3. TRACKING	The computer is in the test condition. The tracking test and not standby relays are energized and ground is made available to the zero check and orient circuits. The outputs of the target coordinate converter are made available to the intercept point solver. The position difference circuit of the VELOCITY AND POSITION DIFFERENCE meters is enabled. The $+S$ voltage is made available to the target and missile range data potentiometers. Servo excitation is removed from the computer servos.
4. STEERING	The computer is in the test condition. The steering test and not standby relays are energized. The S_y voltage is connected to the input network of the time-to-intercept servo. Inputs from the STEERING STATIC TEST switch are made available to the closing speed solver, the target

Table I. COMPUTER CONDITION switch operation (cont).

<u>Position</u>	<u>Condition</u>
4. STEERING (cont)	steering differentiators, and the missile differentiators. Servo excitation is applied to the computer servos and the +S-voltage is removed from the target and missile range data potentiometers.
5. PRELAUNCH AND INITIAL TURN	The computer is in the test condition. The prelaunch test and not standby relays are energized. Inputs from the PRELAUNCH AND INITIAL TURN STATIC TEST switch are made available to the intercept-point solver, the critical turn angle solver, and the target prelaunch differentiators. Servo excitation is applied to the computer servos and the +S-voltage is removed from the target and missile range data potentiometers.

3. SEQUENTIAL SWITCHING

The following switching takes place in sequence, when the computer is in the ACTION condition, under control of the signals listed in table II.

Table II. Sequential switching.

<u>Signal</u>	<u>Origin</u>	<u>Effects in computer</u>
1. Target tracked	TRACKED button, target tracking radar console.	<p>a. Target differentiators are enabled.</p> <p>b. The 4 second electronic settling timer is started.</p> <p>c. The dead time unit motor is started</p> <p>d. The synthetic voltage input from GYRO AZIMUTH voltage divider is disconnected, target position data is connected to intercept point solver.</p> <p>e. A_G, B-, and t-servos now start prelaunch computations.</p> <p>f. The horizontal board pen plots target position, if PLOTTING CONTROL is at PLOT.</p>

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<u>Signal</u>	<u>Origin</u>	<u>Effects in computer</u>
2. Computer settled	Relay in computer which operates when 4-second settling timer has timed out, and t- and AG servos have ceased slewing.	<ul style="list-style-type: none"> a. The horizontal board pen plots intercept point position, if the plotting board condition switch is at plot. b. The altitude board pen plots intercept point position, if the plotting board condition switch is at plot.
3. Missile tracked	AGC monitor or TRACKED button, missile-tracking console (This signal is variable and may occur before or after target tracked, but it must occur before ready-to-fire.)	<ul style="list-style-type: none"> a. The intercept-point solver amplifier inputs are switched from launcher-to-target radar parallax to missile position data. b. The missile tracked signal is sent to event recorder.
4. Ready-to-fire	Relay in battery control console, which operates when missile is tracked, computer is settled, and target identified as foe.	
5. Fire	FIRE switch, battery control console.	<ul style="list-style-type: none"> a. The dead-time unit clutch is engaged and the dead time potentiometer shaft starts. b. The AG servomotor is de-energized and the brake is applied. c. The fire signal is sent to the event recorder and to the plotting boards. d. The 1.75-second electronic timer is started in the launcher control trailer.
6. Fire + 2 seconds (lift-off)	Timer in launcher control trailer (1.75-second).	<ul style="list-style-type: none"> a. Servos in the missile are allowed to catch up to last data from AG servo in computer.

<u>Signal</u>	<u>Origin</u>	<u>Effects in computer</u>
		<ul style="list-style-type: none"> b. Launch order is given and missile booster squib is ignited. Shortly thereafter, missile lift off occurs.
7. Missile-away	Missile-away detector in computer (H_M amplifier).	<ul style="list-style-type: none"> a. Missile differentiators are enabled. b. The missile-away + 4-second delay timer is started. c. The LAUNCH indicator light is lit on the battery control console. d. The altitude and horizontal plotting boards are switched to plot the missile and target positions. e. Final inputs are applied to the initial-turn section. f. The missile away signal is sent to the event recorder.
8. Fire + 7	Cam operated switch in dead-time unit.	The dead-time unit resets.
9. Missile away + 4 seconds (roll stabilization)	Relay in computer which operates when the missile away + 4 second delay time has timed out.	<ul style="list-style-type: none"> a. The prelaunch section computation for time-of-flight is removed from t-servo. b. The second-per-second bias network is connected to the t-servo. c. The fin order solver is connected through to missile-tracking radar. d. The 7g dive order is transmitted to the missile.

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<u>Signal</u>	<u>Origin</u>	<u>Effects in computer</u>
		<ul style="list-style-type: none"> e. Missile position data is removed and launcher-to-target radar parallax connected to intercept point solver. f. Initial turn section amplifiers are switched to HOLD. After a short delay, initial turn section orders are transmitted to the missile.
10. Radar cleared	Relay in computer which operates when Y_G first goes positive.	If a skirting turn was required, it is removed and a zero turn order is substituted.
11. On trajectory	Relay in computer which operates when error S_C first becomes positive.	<ul style="list-style-type: none"> a. The 7g dive is removed and the steering error along climb axis S_C is applied. b. The gt bias is applied to steering error computation. The missile now flies $\frac{1}{2}g$ lift trajectory. c. The steering error along missile velocity vector S_V is connected to the t-servo.
12. Reception of both radar-cleared and on trajectory signals	Relay in the computer that deenergized.	<ul style="list-style-type: none"> a. The initial-turn section is disabled. b. All steering orders from the steering section are applied.
13. t = 24 seconds	Cam-operated micro-switch in t servo. Operates at t = 24 seconds.	<ul style="list-style-type: none"> a. The t-servo is switched from coarse to fine potentiometer cards. b. Half-order shaping is applied, giving 1 second lead equalization.

<u>Signal</u>	<u>Origin</u>	<u>Effects in computer</u>
14. t 10 seconds	Cam-operated micro-switch in t-servo. Operates at t 10 seconds.	Full order shaping is applied giving 2-second lead equalization.
15. Burst enable	Cam-operated micro-switch in t-servo. Operates at t = 250 milliseconds.	<ul style="list-style-type: none"> a. The burst order circuit is enabled. b. S_y is disconnected from the t-servo, which then runs down at a second-per-second rate. c. Three channels in the event recorder which plot target velocity components are switched to plot apparent miss distance at burst.
16. Burst	Relay in comparator amplifier output operates when t-voltage - burst time bias.	<ul style="list-style-type: none"> a. The burst order is sent to the missile radar. b. The BURST lights are lit on the battery control console, missile control console, and radar control console. c. The burst signal is sent to the event recorder.
17. Apparent miss distance at burst holding	Cam-operated microswitch in t-servo operates at t - 0 seconds.	<ul style="list-style-type: none"> a. The apparent miss distance at burst circuit is switched to HOLD. b. Apparent miss distance at burst and burst order circuit lockup when t-servo starts slewing.
18. Computer reset	Loss of missile beacon signal.	The computer is returned to prelaunch section configuration. The time servo will go:

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<u>Signal</u>	<u>Origin</u>	<u>Effects in computer</u>
18. (cont)		<ul style="list-style-type: none"> a. To the 44.57-second standby position if the target-tracked signal is removed. b. To solution for prelaunch time computation for time of flight, if target-track signal is on.
19. Burst release	Time slew control circuit monitoring time servomotor drive voltage.	Locks on burst enable and apparent miss distance at burst circuits are released, restoring them to prelaunch configuration.

The following signals do not normally occur in sequence, but will occur under certain conditions.

20. Missile reject	Cam-operated monitor switch in dead-time unit. Operates 5 seconds after FIRE signal.	The missile reject signal is transmitted to other locations if the missile-away signal has not been received.
21. Gimbal limit	Cam-operated switch in turn angle servo. Operates if turn angle reaches plus or minus 1,260 angular mils (approximately 70°).	<ul style="list-style-type: none"> a. A 2.4lg turn order is sent to the missile, directing the turn angle to decrease. b. The gimbal limit order is sent to the event recorder. c. The GIMBAL LIMIT light on the battery control console is lit.

4. COMPLETION

This completes the sequence of events in the computer. The computer is now ready for the next problem.

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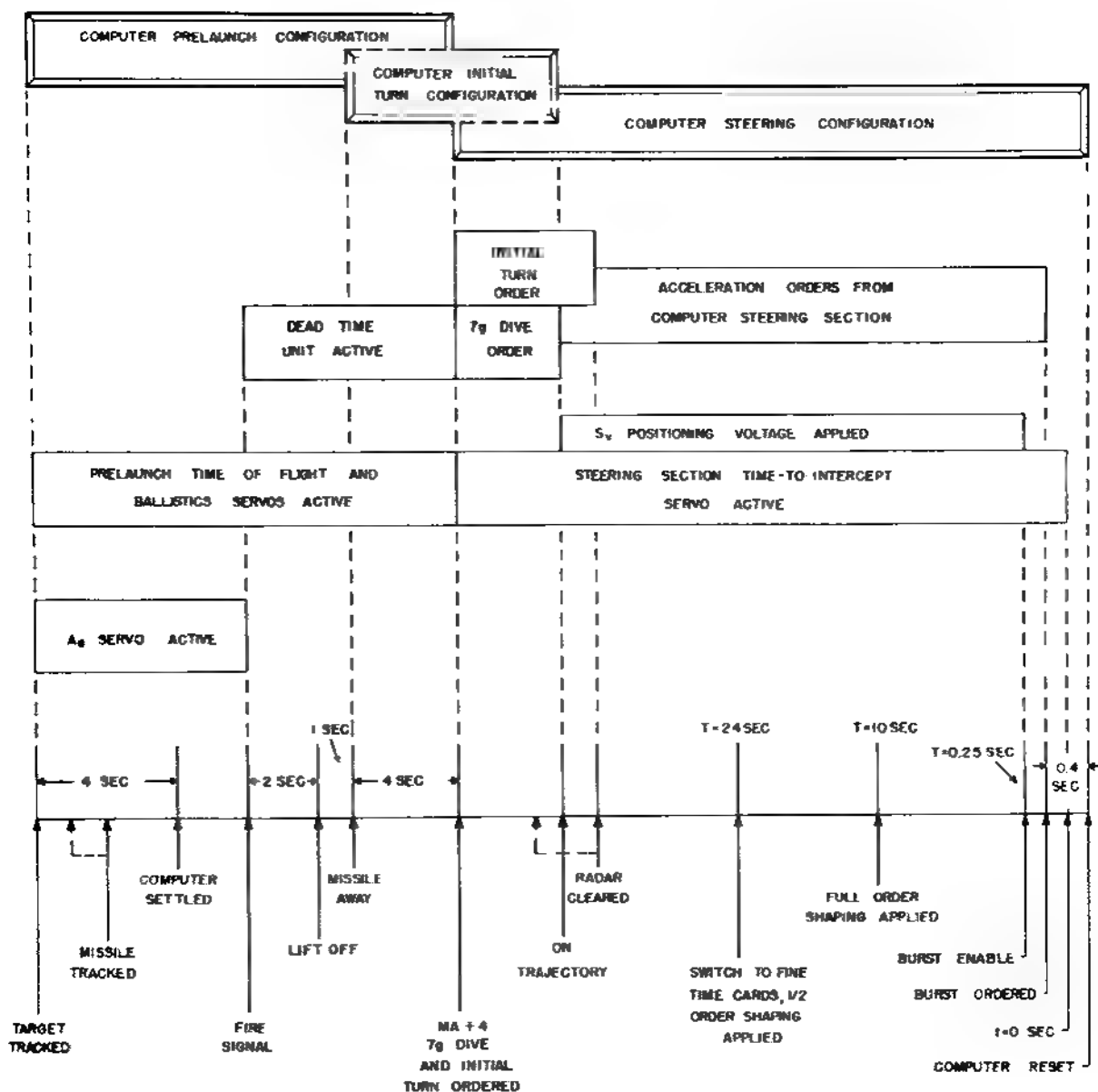


Figure 1. Sequence of events.

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APPENDIX II

STUDY QUESTIONS

1. What is the polarity of the voltage from the $-Y_T$ amplifier for a target located in the third quadrant?
2. A target is located at 4,800 mils azimuth, 800 mils elevation, and 14,140 yards slant range. If the TTR is tracking this target, what is the amplitude and polarity of the voltage data (X_T , Y_T , H_T) sent to the intercept point solver?
3. If the geometric center of the launcher area is located in the fourth quadrant with respect to the TTR and at a higher elevation than the battery control area, what is the polarity of the launcher parallax voltage sent to the intercept point solver?
4. When are $-H_M$ data first sent to the missile differentiator?
5. Which amplifiers in the missile coordinate converter (if any) use precision zero setting?
6. A target is traveling south away from the TTR position at a speed of 500 yards per second. What is the amplitude and polarity of the voltage output data of the \dot{Y}_p differentiator?
7. When is the target prelaunch differentiator enabled?
8. List the units to which \dot{X}_p data are sent.
9. List the units receiving $+S$ -voltage.
10. If the voltage at pin 8 of V20 (162D6) should rise, explain how the $+S$ -amplifier and voltage regulator function to return the voltage at pin 8 to its correct value.
11. \dot{X}_p is changing at 125 yards per second. What is the voltage at terminal 571 (47C12)?
12. The output of the $-X_I$ amplifier is a positive voltage. The output of the $-Y_I$ amplifier is a negative voltage. In what quadrant is the intercept point located?

13. An enemy target is approaching the battery position from a point 36,000 yards west, 48,000 yards north, and 36,000 feet above the TTR. The target is traveling toward the TTR with a ground speed of 1,000 mph. (Hint: Use 3:4:5 triangle relationship to find \dot{X}_P and \dot{Y}_P .) The target is diving at a rate of 5 yards per second. The designated launcher is 1,000 yards east, 2,000 yards south, and 100 yards above the TTR. The time servo dial reads 33 seconds. Compute X_I , Y_I , and H_I .

14. Using data given in problem 3, compute the values of X_I , Y_I , and H_I , 4 seconds after the FIRE switch has been operated, if the target velocity is unchanged.

15. At the instant described in problem 4, are the time gears moving?

16. If the A_G is 2,400 mils and Y_I is 30,000 yards, what is the voltage at pin 24 of S303 (29D5)?

17. For problem 6, what is the voltage at terminal 4 of the t_{p1} input network (49C8)? (Give both the quantity and voltage.)

18. If the potential at terminal 611 is 27 volts and the potential at terminal 614 is +27 volts, what is the reading on the A_G dial?

19. What are the inputs to t_{p1} and t_{p2} (49D8)?

20. What is the effect on the t servo of a negative output from t_{p1} ?

21. What term designates the radius of a constant-time circle?

22. What is the sum of $R_B + D_B \cos B$?

23. What is the formula of R_B in terms of t ?

24. How is R_B synthesized?

25. What equation is used in the time-of flight predictor to solve for t ?

26. What is the purpose of the $+t$ -amplifier and $-t$ -amplifier?

27. Why is T_F-6 (83C1) used as an input to the $-t$ amplifier?

28. What causes the t -slew motor to drive the t -servomechanism?

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29. What is the maximum rate at which the servomotor can drive the t-servomechanism?
30. At what rate does the slew motor drive the t-servomechanism?
31. What is the maximum $+R_I$ input to t_{p1} and t_{p2} ? (Derive from R_B and $D_B \cos B$.)
32. What are the two purposes of the initial turn section?
33. Name the seven inputs to the initial turn section and state whether they are mechanical or voltage inputs.
34. The launcher is 2,000 yards east and 4,000 yards south of the MTR. The launcher-to-radar azimuth is 5,928 mils. The A_G is 5,000 mils.
- a. What is the polarity of CTA?
 - b. What polarity of DTA should be chosen?
 - c. What is the polarity of STA?
 - d. What turn angle must the missile fly?
35. The CTA is +85 mils. The DTA is 155 mils. Find the STA. Should the missile fly with a zero-degree initial turn angle or with a skirting turn angle?
36. The computer is conditioned to the prelaunch and initial turn static test mode (refer to 106C1). Switch S4 (97D2) is in position 4. The null voltage test set dial reading at terminal 180 (97B7) in the amplifier cabinet is +400. The dial on the CA servo reads 1,600 mils.
- a. What will be the reading on the NVTS at t_{p1} (29A7) when S4 (29A7) is in the EXT position and S3 (29B6) is in the +DTA position?
 - b. Is K105 (98D8) energized or deenergized?
 - c. What is the magnitude and polarity of STA?
 - d. Is K108 (98A8) energized or deenergized?
 - e. Is K121 (108A8) energized or deenergized?

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